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MULTIWALL RADOME ANALYSIS PROGRAM

Air-to-Ground Analysis Group
Reconnaissance and Weapon Delivery Division

February 1976

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AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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This report describes a computer analysis tool for calculating the electrical transmission and reflection properties of a multiwall radome. The radome program may be used with a suitable antenna program to estimate the effects of the radome on the antenna pattern.

The analysis tool is comprised of two programs, a radome-geometry program, RADOME, and a flat-panel analysis program, WAVES2. The geometry program calculates the incidence angle for each ray (a ray represents the radiated RF power from each antenna element) at the radome wall. The output data (Contd)

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Abstract continued:

from the geometry program, RADOME, serves as input to the flat-panel program. The flat-panel program then calculates the electrical transmission and reflection parameters of the radome for each ray. These parameters may then be used with a suitable free-space antenna pattern simulation program, and the resultant antenna pattern in the presence of the radome can be computed.

FOREWORD

The computer program in this report was written for the Air Force Avionics Laboratory's Electronically Agile Radar (EAR) program. The work was performed by personnel from the Air-to-Ground Analysis Group, Mr. Richard M. Reeves, Group Leader, Analysis and Evaluation Branch, Reconnaissance and Weapon Delivery Division. Mr. Robert M. Blumgold was the principal investigator. Special acknowledgment is due Dr. James McDougal of the Air-to-Air Analysis Group, Mrs. Georgeanne Chitwood of the Air-to-Ground Analysis Group, and to Mr. Clyde Hoots of the Brunswick Corp., Marion, Va., for their valuable assistance during this study.

Publication of this report does not constitute Air Force approval of the report findings or conclusions. It is published only for the exchange and stimulation of ideas.

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LIST OF SYMBOLS

x_{at}, y_{at}, z_{at}	Antenna coordinates of point of interest
R	Magnitude of the vector from antenna phase center to point of interest
θ_e, θ_a	Antenna elevation and azimuth scan angles
λ	Wavelength
D	Antenna aperture
x_{ij}, y_{ij}, z_{ij}	Antenna coordinates of the i, j element, where i and j are the row and column number respectively
$\alpha_{ij}, \beta_{ij}, \gamma_{ij}$	Are the direction cosines from each element to point of interest
R_{ij}	Vector from i, j element to point of interest
X_r, Y_r, Z_r	Coordinate system used in defining radome contour
y_i, z_i	Coordinates of radome stations
ΔYR_i	y axis location of radome station i relative to the antenna phase center
α'	Angle between the antenna phase center to point of interest and the YR axis
z_{ir}	Z coordinate of radome station i
x_a, y_a, z_a	Antenna coordinate system
θ	Rotation angle about the YR axis
θ_I	Initial rotation angle about the YR axis
$\Delta\theta$	Incremental change in the rotation angle about the YR axis
x_o, y_o, z_o	Radome coordinates of the antenna phase center
$\alpha_j, \beta_j, \gamma_j$	Direction cosines of illuminated area of the radome
$X_{\theta j}, Y_{\theta j}, Z_{\theta j}$	Are the components of the vector from the antenna phase center to the radome surface
$TMAG_{\theta j}$	Magnitude of the vector from the antenna phase center to the illuminated area of the radome

X_{mn}, Y_{mn}, Z_{mn}	Coordinates of array elements
m, n	Antenna array element row and column numbers respectively
α, β, γ	Direction cosines for the point of interest relative to the antenna phase center
α_{ij}, β_{ij}, γ_{ij}	Direction cosines of the ray from each element to the illuminated area of the radome
B_i-B_n	Least squares fit coefficients for radome contour
$\underline{n}_R$	Unit normal to radome surface (radome coordinates)
$\underline{n}_A$	Unit normal to radome surface (antenna coordinates)

SECTION I

INTRODUCTION

1. GENERAL

This technical report describes a digital computer analysis program which will calculate the electrical transmission and reflection properties of a multiwall radome. The radome program may be used with a suitable antenna program to estimate the effects of the radome on the antenna pattern.

The analysis program is comprised of two programs, a radome-geometry program, RADOME, and a flat-panel analysis program, WAVES2. The radome-geometry program calculates the incidence angle for each ray (a ray represents the radiated RF power from each antenna element) at the radome wall. The output from the geometry program serves as an input to the flat-panel program. The flat-panel program, WAVES2, calculates the electrical transmission and reflection parameters of the radome for each ray, using the input from RADOME. These parameters may then be used with a suitable free-space antenna pattern simulation program, and the resultant antenna pattern in the presence of the radome can then be computed.

This technical report documents the radome-geometry program, RADOME, and the necessary modifications to the flat-panel program, WAVES2. A complete description of the flat-panel program may be found in AFAL-TR-67-191.

2. DEFINITION OF THE PROBLEM

The specific problem which generated the radome analysis program involved position fixing accuracy using an aircraft forward-looking multimode radar. For example, a position fix is to be made of a ground target at location "A" (Figure 1). The antenna electrical boresight is steered to the estimated azimuth, θ_a, and elevation, θ_e, of the target. Then by using the antenna's monopulse patterns, an accurate measurement of the target's location relative to the antenna electrical boresight may be determined. However, due to the distortion of the antenna's free-space pattern in the presence of the radome, an error exists in determining the azimuth and elevation location of the target relative to the steered direction of the antenna electrical boresight. Therefore, to minimize the measurement inaccuracies it is desirable to estimate the antenna pattern in the presence of the radome and use this information to correct the measurement of target location.

A table of correction terms may be generated by using the radome analysis program and a suitable antenna pattern simulation program. A set of azimuth and elevation scan angles can be used as inputs to the geometry program, RADOME, to generate the incidence angles for the ray from each element in the antenna array and the information stored on magnetic tape. The magnetic tape storage is required because of the large number of rays involved and the computation time required. The incidence angle information from RADOME on the magnetic tape is then input to the flat-panel program, WAVES2. In the WAVES2 program the transmission and reflection parameters are calculated for each element in the antenna array for given antenna electrical boresight azimuth and elevation angles. Transmission and reflection parameters calculated by

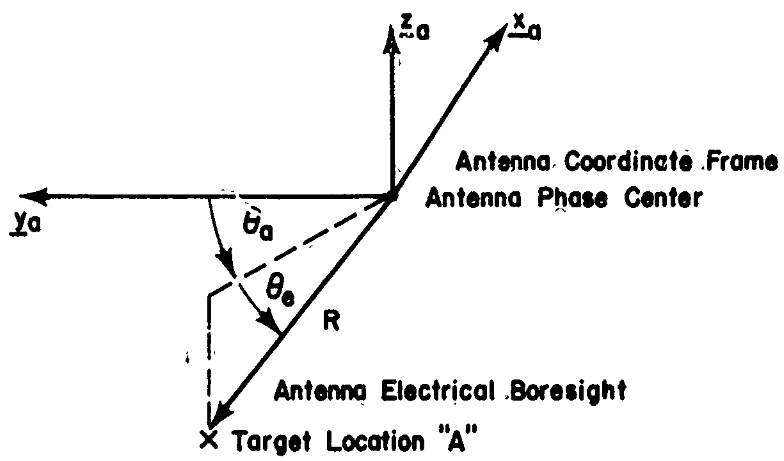

Figure 1. Position Fix

the WAVES2 program can then serve as inputs to a suitable antenna pattern simulation program, and a table of correction terms (i.e., boresight shift) can be generated and subsequently used to correct the measurement of the target's azimuth and elevation location.

3. REPORT ORGANIZATION

This technical report is divided into eight sections. Section two describes items included in the documentation, method of analysis, equations involved, geometry, input and output parameters. Section three gives the variables, common, labeled common, dimension, and data statements for the main program and all subroutines. Section four outlines the input deck structure, defines the required data, and establishes the format of the input data cards. Section five presents a sample problem with a typical set of data describing the radome, gives the user's output requirements, lists the printout, and describes the data stored on magnetic tape for later use. Flowcharts and program listings have been included. Section six describes the Flat-Panel Program and Section seven offers recommendations for best utilization of the routine.

SECTION II

DEVELOPMENT OF THE RADOME-GEOMETRY PROGRAM (RADOME)

1. METHOD

The RADOME program applies the techniques of ray tracing to an antenna array and a multiwall radome, and calculates the incidence angles of antenna radiation at the radome inner surface. The incidence angles are needed to compute reflection and transmission parameters which were accomplished by program WAVES2.

2. DERIVATION OF EQUATIONS

The rectangular coordinates of the point of interest (a point at which the antenna boresight is directed) are computed from the given scan angles of the antenna's electrical boresight. The antenna coordinate system is defined by a unit vector, $\underline{y}_a$, normal to the face of the antenna array, a unit vector $\underline{x}_a$, which is parallel to the face of the array and at a right angle to $\underline{y}_a$, and a unit vector $\underline{z}_a$, parallel to the array face and perpendicular to $\underline{x}_a$ and $\underline{z}_a$. The aximuth angle, θ_a, is defined in the plane determined by $\underline{x}_a$ and $\underline{y}_a$. The elevation angle θ_e is defined in a plane perpendicular to the one formed by $\underline{x}_a$ and $\underline{y}_a$.

The location of the antenna array elements is computed in antenna coordinates, one quadrant of the array at a time. The central elements of the array are spaced one quarter of a wavelength from the phase center of the array. The antenna aperture is assumed to be circular, with the elements arranged in a rectangular grid out to the aperture's edge. The maximum number of rows and columns is specified as a user

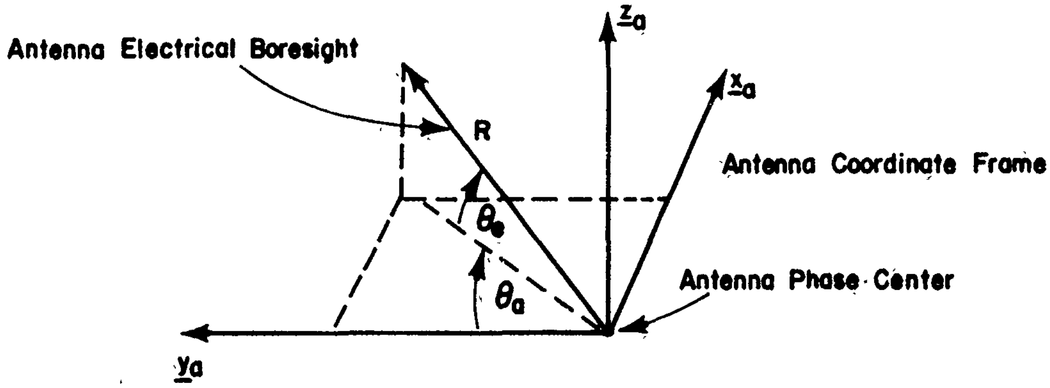

Figure 2. Antenna Scan Angles

Then,

$$x_{at} = R \cos\theta_e \sin\theta_a \tag{1}$$

$$y_{at} = R \cos\theta_e \cos\theta_a \tag{2}$$

$$z_{at} = R \sin\theta_e \tag{3}$$

input. The coordinates of those elements that are contained within a given aperture radius are stored for later use (Figure 3).

The antenna coordinate system is a rectangular coordinate system with its origin at the antenna phase center. In antenna coordinates the location of the (i,j)-element is denoted by x_{ij}, y_{ij}, z_{ij}.

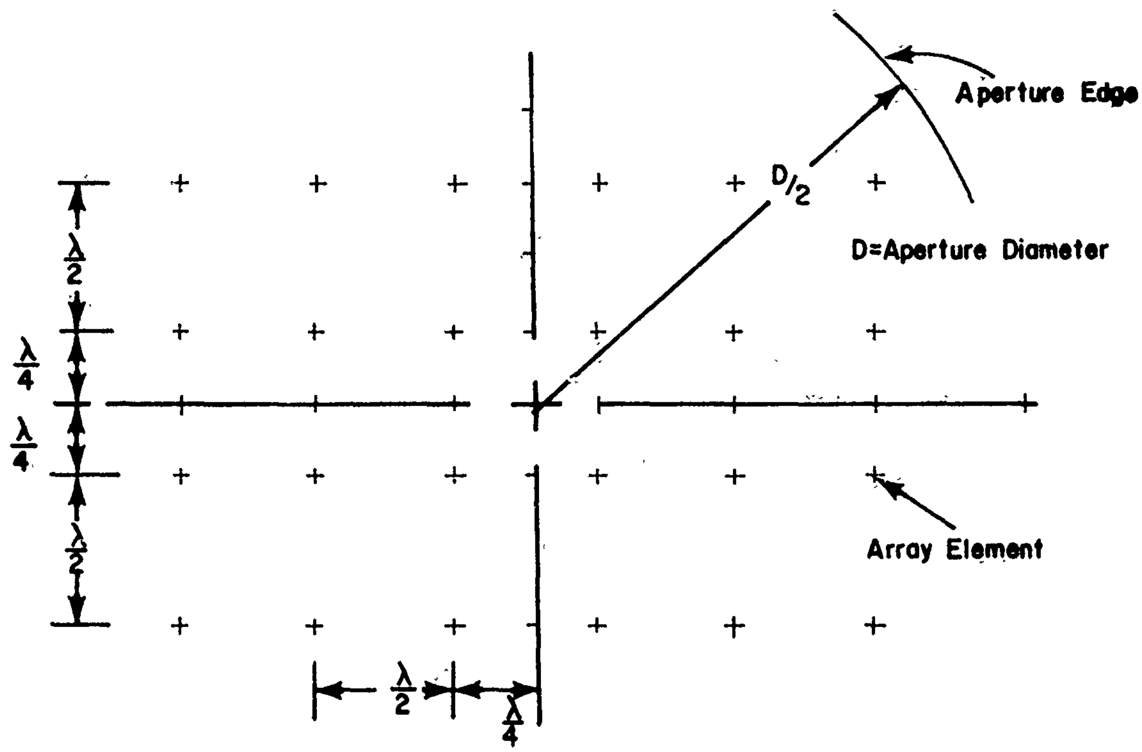

Figure 3. Array Element Geometry

The direction cosines of a ray from array element (i,j) to the point of interest are determined as follows:

$$\alpha_{ij} = \frac{(x_{at} - x_{ij})}{|R_{ij}|} \tag{4}$$

$$\beta_{ij} = \frac{(y_{at} - y_{ij})}{|R_{ij}|} \tag{5}$$

$$\gamma_{ij} = \frac{(z_{at} - z_{ij})}{|R_{ij}|} \tag{6}$$

where

$$|R_{ij}| = \left[(x_{at} - x_{ij})^2 + (y_{at} - y_{ij})^2 + (z_{at} - z_{ij})^2\right]^{1/2} \qquad (7)$$

and $\quad i$ = row number

$\quad j$ = column number

The radome is a body of revolution over the complete window area. The radome contour is generated by rotating the curve (Figure 4), representing the outside mold line, about the YR axis. Coordinates of the radome contour y_i and z_i are given by the manufacturer in tabular form. Data cards containing the y_i and z_i coordinates of points on the radome contour are used as inputs to the computer program. Usually, points are spaced more closely together on the YR axis nearer the front of the radome. The radome axis, YR, and the antenna axis, $\underline{y}_a$, are assumed to be parallel. (Due to program storage limitations it is necessary to store only the coordinates of the radome surface that will encompass the projected surface area of the antenna aperture in the given scan direction.)

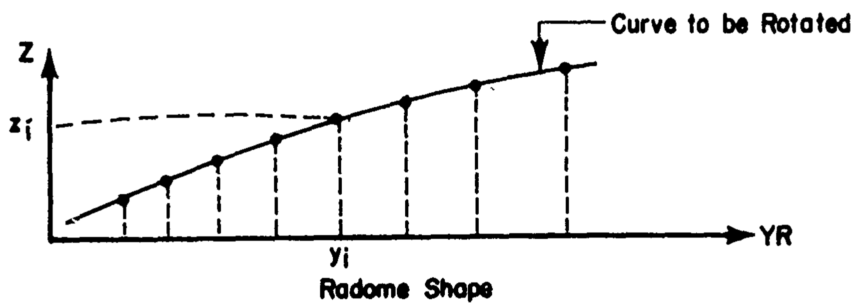

Figure 4. Radome Outside Mold Line Contour

The angle (α') between a ray from the central area of the antenna aperture and the YR axis is used to determine the region where this ray passes through the radome's surface (Figure 5). The angle (α') is determined from the following equations.

$$x = x_{at} - x_{11} \tag{8}$$

$$y = y_{at} - y_{11} \tag{9}$$

$$z = z_{at} - z_{11} \tag{10}$$

$$|R| = \left[x^2 + y^2 + z^2\right]^{1/2} \tag{11}$$

$$\alpha' = \cos^{-1}\left[\frac{y}{|R|}\right] \tag{12}$$

The interval ΔYR_i on the YR axis is obtained by subtracting the YR coordinate of the ith radome contour point from the antenna's phase center location.

$$\Delta YR = Ya - y_i \tag{13}$$

Beginning with the first point of the radome contour near the tip, points are tried until the quantity $Z = \Delta YR_i \tan(\alpha')$ is less than the Z coordinate of the ith radome contour point. Once this point is determined, i.e., $(Z_i - Z) > 0$, the sixty radome contour points that are symmetric about this central point are determined and used to encompass

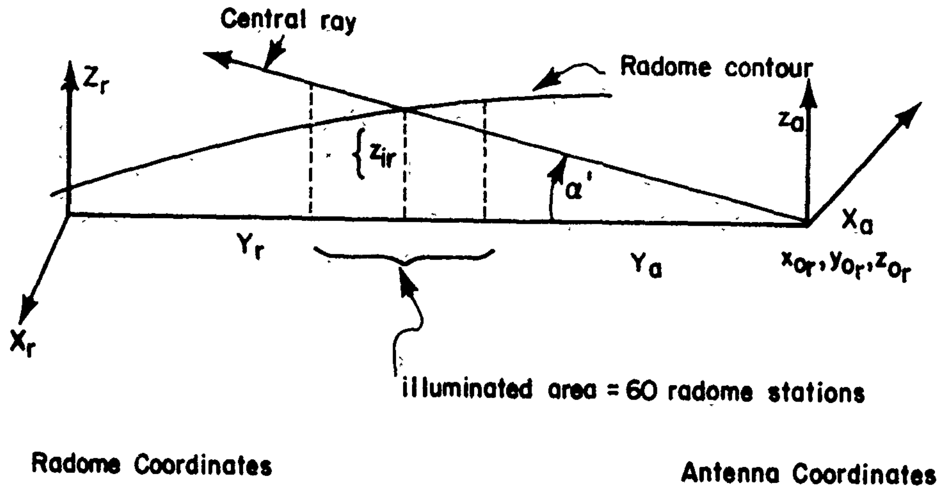

Figure 5. Radome Area Illuminated by the Antenna

the projected area of the antenna aperture. The value of sixty points was chosen from empirical results. If the points are too close to the tip of the radome, then we choose sixty points beginning with the point closest to the radome tip as we progress toward the rear of the radome. Similarly, if the points are too close to the rear, then sixty points are used beginning with the last point and working forward.

The surface region of the radome encompassing the projected area of the antenna aperture in a given scan direction is determined through the use of the following equations (Figure 6).

$$\theta = \theta_I + \Delta\theta \tag{14}$$

where θ_I is the initial rotation angle about the YR axis, and

$\Delta\theta$ is the incremental change in the rotation angle

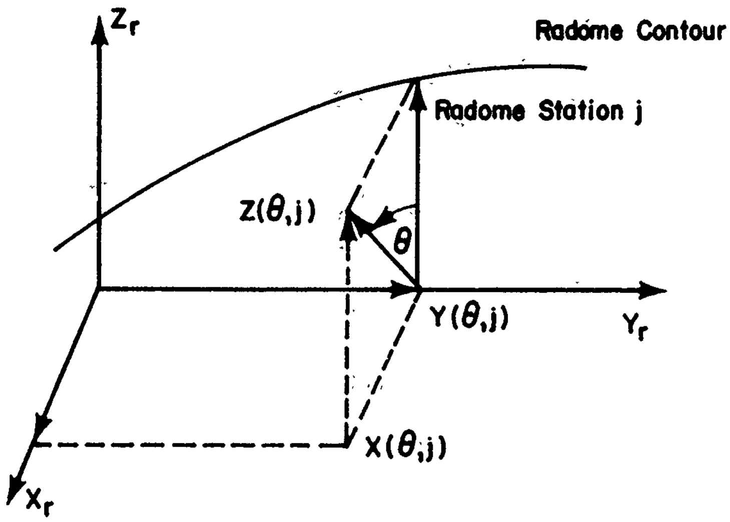

Figure 6. Radome Station Coordinates

The program allows ninety values of (θ). The incremental change ($\Delta\theta$) is a user-supplied input, and a suggested value based on empirical results is two degrees. The initial value of the rotation angle (θ_I), also supplied by the user, is chosen on the basis of ($\Delta\theta$) and by program results so that the determined region of the radome encompasses the projected antenna aperture area.

Thus, provision is made for as many as sixty radome surface elements (radially) and by ninety surface elements (rotationally), or 5400 possible surface elements defining the projected aperture area of the antenna on the radome's surface. In general, the projected antenna aperture will occupy less than this number of radome surface elements.

The required surface region of the radome is determined by the following equations:

$$X(\theta, j) = z_j \sin\theta \qquad (15)$$

$$Y(\theta, j) = y_j \qquad (16)$$

$$Z(\theta, j) = z_j \cos\theta \qquad (17)$$

where

y_j, z_j — are the coordinates of the jth point on the radome contour

The antenna coordinates of the region of interest are determined as follows:

$$X\theta_j = -(X(\theta, j) - x_o) \qquad (18)$$

$$Y\theta_j = y_o - Y(\theta, j) \qquad (19)$$

$$Z\theta_j = Z(\theta, j) - z_o \qquad (20)$$

where

x_o, y_o, z_o — are the radome coordinates of the antenna phase center

The direction cosines of the illuminated area of the radome relative to the antenna phase center are:

$$\alpha_j = \frac{X\theta_j}{TMAG\theta_j} \tag{21}$$

$$\beta_j = \frac{Y\theta_j}{TMAG\theta_j} \tag{22}$$

$$\gamma_j = \frac{Z\theta_j}{TMAG\theta_j} \tag{23}$$

$$TMAG\theta_j = \left[X^2_{\theta_j} + Y^2_{\theta_j} + Z^2_{\theta_j} \right]^{1/2} \tag{24}$$

The antenna elements to the illuminated area direction-cosines are:

$$\alpha_{m,n} = \frac{\Delta X_{m,n}}{|R_{m,n}|} \tag{25}$$

$$\beta_{m,n} = \frac{\Delta Y_{m,n}}{|R_{m,n}|} \tag{26}$$

$$\gamma_{m,n} = \frac{\Delta Z_{m,n}}{|R_{m,n}|} \tag{27}$$

where

$$\Delta X_{m,n} = X\theta_j - X_{m,n} \tag{28}$$

$$\Delta Y_{m,n} = Y\theta_j - Y_{m,n} \tag{29}$$

$$\Delta Z_{m,n} = Z\theta_j - Z_{m,n} \tag{30}$$

$$R_{m,n} | = \left[\Delta X^2_{m,n} + \Delta Y^2_{m,n} + \Delta Z^2_{m,n} \right]^{1/2} \tag{31}$$

for which $X\theta_j, Y\theta_j, Z\theta_j$ are the antenna coordinates of a subelement of the illuminated area

$X_{m,n}, Y_{m,n}, Z_{m,n}$ are the antenna coordinates of each element in the antenna array

and m,n are the row and column number of the antenna elements

The next step is to find the radome subelement intersected by a ray in the boresight direction from each antenna element. For each element in the antenna array, a search of the illuminated area of the radome surface is made, beginning with the first radome station. The direction cosines from the element to the radome surface are compared to those of the central ray. If the direction cosines are within a given tolerance, i.e., the two rays are pointing in approximately the same direction, then this point on the radome surface is used to indicate where the ray passes through the radome. The direction cosine for the angle between the ray from the element to the surface and the central ray is

$$DC = \alpha\alpha_{ij} + \beta\beta_{ij} + \gamma\gamma_{ij} \tag{32}$$

where α,β,γ = direction cosines for the central ray, and

$\alpha_{ij},\beta_{ij},\gamma_{ij}$ = direction cosines of the ray from the element to the window area.

The ray is parallel to the antenna electrical boresight when "DC" is equal to one. The tolerance is set to slightly less than one. And, the coordinate of the radome surface that is used is the point where "DC" is greater than the given tolerance.

Next, the normal to the surface of the illuminated area is determined for each coordinate where a ray intersects the radome surface. A least squares curve fitting routine (CURFIT) is used to fit the radome outside mold contour data to a sixth degree polynomial in radome coordinates (Figure 2). A transformation is then made to antenna coordinates, so that

$$f(y) = B_n + B_1 y + B_2 y^2 + B_3 y^3 + B_4 y^4 + B_5 y^5 + B_6 y^6 \qquad (33)$$

An equation in x,y,z can be found for the surface of the illuminated area of the radome, when given that the radome is a body of revolution (Figure 7). Thus,

$$R = f(y) \qquad (34)$$

$$x^2 + z^2 = R^2 \qquad (35)$$

$$x^2 + z^2 = f^2(y) \qquad (36)$$

$$x^2 + z^2 - f^2(y) = 0 \qquad (37)$$

$$F = x^2 + z^2 - f^2(y) \qquad (38)$$

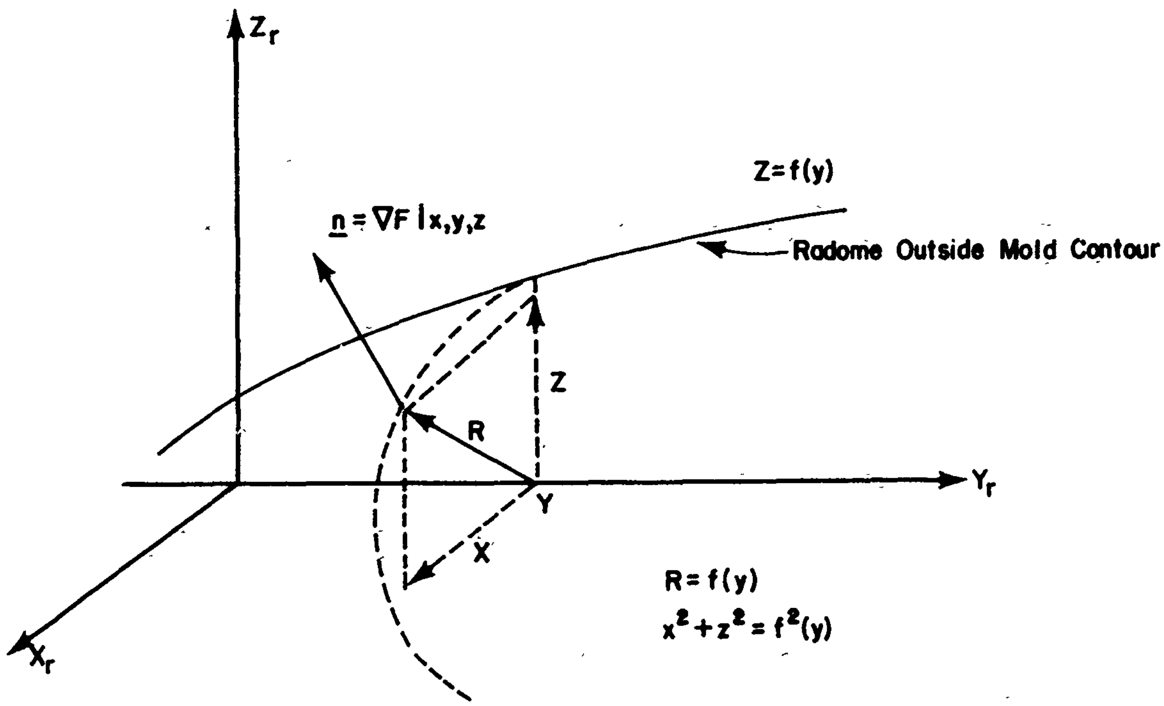

Figure 7. Determination of Normal to Radome Surface

The normal to the surface is given by

$$\underline{N} = \nabla F$$

$$\underline{N} = 2x\,\underline{i} + 2z\,\underline{k} - 2\,f(y)\left(\frac{df(y)}{dy}\right)\underline{j} \tag{39}$$

where

$$\frac{df(y)}{dy} = B_1 + 2B_2 y + 3B_3 y^2 + 4B_4 y^3 + 5B_5 y^4 + 6B_6 y^5 \tag{40}$$

To obtain the unit normal, first define

$$\underline{N}^* = 1/2\,\underline{N} = x\,\underline{i} + z\,\underline{k} - f(y)\frac{df(y)}{dy}\,\underline{j} \qquad (41)$$

$$|N^*| = \left\{x^2 + z^2 + \left[f(y)\frac{df(y)}{dy}\right]^2\right\}^{1/2} \qquad (42)$$

Then the unit normal, in radome coordinates, is stated by

$$\underline{n}_R = \frac{N^*}{|N^*|} = \alpha_{iR} + \beta_{jR} + \gamma_{kR} \qquad (43)$$

In antenna coordinates, the unit normal is

$$\underline{n}_A - \alpha_{\underline{i}A} - \beta_{\underline{j}A} + \gamma\,\underline{K}_A \qquad (44)$$

The incidence angle of the ray from each element to the radome surface is determined by taking the dot product of the unit vector from the array element to the surface, and the normal to the surface at the point of intersection. Thus,

$$x_{ij} = \underline{r}_{ij} \cdot \underline{n}_A \qquad (45)$$

$$\theta_{ij} = \cos^{-1}(x_{ij}) \qquad (46)$$

where $\underline{r}_{ij}$ is the unit vector of the ray from the i, j, element to the intersection point on the surface

$\underline{n}_a$ is the unit normal curve at the point of intersection

and θ_{ij} is the incidence angle for the ray from an array element.

The sequence of events we have described in this section is programmed in RADOME. The end product is the incidence angle of each ray at the radome surface. This is used in program WAVES2 to calculate reflection and transmission properties of the radome for each ray.

3. INPUT

Program I/O (Input/Output) is described in Section III and examples are given in Section V. Briefly, the input consists of the following items:

a. Number of radome stations
b. Initial rotation angle, incremental angle, and total number of angles
c. Antenna elevation and azimuth scan angles
d. Antenna phase center location in radome coordinates
e. Number of computer runs to be made
f. Wavelength
g. Aperture radius
h. Maximum number of rows and columns in the antenna array
i. Radome outside mold station coordinates

4. OUTPUT

Program output is in the form of a tabular printout:

a. Row and column number for each array element whose ray passes through the radome wall

b. Incidence angle for each ray

c. Number of rays passing through the radome wall

d. Elevation and azimuth scan angles

e. Number of radome stations

f. Initial rotation angle, incremental angle, and number of angles

g. Antenna phase center location in radome coordinates

SECTION III

GENERAL ANALYSIS PROGRAM DESCRIPTION

1. THE MAIN PROGRAM

The analysis program is written in FORTRAN IV for a CDC 6600 CYBER 74, operating under SCOPE 3.4.1. The main program is primarily an executive routine which calls a series of subroutines. The subroutines are organized into the following functional groups:

1. Antenna element location, ARRAY
2. Element to point of interest direction cosines, DIRET
3. Window area surface coordinates, SFILE
4. Illuminated radome stations, START
5. Element to radome direction cosines, DIRER
6. Normal to window area, NORM
7. Incidence angles, INCID

The Main Program, PROGRAM RADOME (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7), is a routine which reads the following input variables:

NSEC, number of radome stations

ANGI, initial rotation angle

ANGD, incremental rotation angle

NANG, number of angular positions

THEL, elevation scan angle

THAZ, aximuth scan angle

COMMON FILE (60,90,3), NSEC,ANGI,ANGD,NANG,AX,AY,AZ

COMMON/BLK1/TGTX,TGTY,TGTZ

COMMON/BLK3/ABGET(45,45,3)

COMMON/BLK20/SW2

AX,AY,AZ antenna phase center location in radome coordinates

2. SUBROUTINES

a. ARRAY

COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN

COMMON/BLK12/RMAX

COMMON/BLK13/IMAX,JMAX

COMMON/BLK20/SW2

DATA XLAMDA/1.2/

DATA RR/18.0/

NUMM,NUMN - maximum allowable number of rows and columns in the antenna array

RMAX - radius of antenna aperture

IMAX,JMAX - actual number of rows and columns in the antenna array

XLAMDA - wavelength (inches)

RR - aperture radius (inches)

EFILE - file of element locations

b. DIRET

COMMON/BLK1/TGTX,TGTY,TGTZ

COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN

COMMON/BLK3/ABGET(45,45,3)

```
COMMON/BLK12/RMAX
COMMON/BLK13/IMAX,JMAX
```

TGTX,TGTY,TGTZ	-	antenna coordinates of point of interest
NUMM,NUMN	-	maximum allowable number of rows and columns in the array
ABGET	-	file of array element to point of interest direction cosines
RMAX	-	maximum radius of antenna aperture
IMAX,JMAX	-	maximum number of rows and columns in the array

c. SFILE

```
COMMON FILE (60,90,3),NSEC,ANGI,ANGD,NANG,AX,AY,AZ
COMMON/BLK4/XY(200),XZ(200)
COMMON/BLK5/NSTART,NFIN
COMMON/BLK20/SW2
DIMENSION FX(90),FY(90),FZ(90)
```

FILE	-	file of antenna coordinates of window area
NSEC	-	number of radome stations
ANGI	-	initial rotation angle
ANGD	-	rotation angle increment
NANG	-	number of incremental angles
AX,AY,AZ	-	radome coordinates of antenna phase center
XY,XZ	-	files of radome stations, Y and Z coordinates

NSTART,NFIN	-	beginning and ending window area radome station numbers
SW2	-	switch set false after first run
FX,FY,FZ	-	radome coordinates of window area

d. START

```
COMMON FILE (60,90,3),NSEC,ANGI,ANGD,NANG,AX,AY,AZ
COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN
COMMON/BLK3/ABGET(45,45,3)
COMMON/BLK4/XY(200),XZ(200)
COMMON/BLK5/NSTART,NFIN
```

FILE	-	defined in SFILE
NSEC	-	"
ANGI	-	"
ANGD	-	"
NANG	-	"
AX,AY,AZ	-	"
XY,XZ	-	"
EFILE	-	defined in ARRAY
NUMM,NUMN	-	"
ABGET	-	defined in DIRET
NSTART,NFIN	-	defined in START

e. DIRER

```
COMMON FILE (60,90,3),NSEC,ANGI,ANGD,NANG,AX,AY,AZ
COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN
```

```
COMMON/BLK3/ABGET(45,45,3)
COMMON/BLK5/NSTART,NFIN
COMMON/BLK6/IFILE(45,45),JFILE(45,45)
COMMON/BLK8/FILEE(45,45,3)
COMMON/BLK12/RMAX
COMMON/BLK13/IMAX,JMAX
DATA TOL/.99939/
```

FILE	-	defined in SFILE
EFILE	-	defined in ARRAY
NUMM,NUMN	-	defined in ARRAY
ABGET	-	defined in DIRET
NSTART	-	defined in START
NFIN	-	defined in START
IFILE	-	file of radome stations for ray intersections
JFILE	-	file of the number of angular increments for a given radome station ray intersection
FILEE	-	file of direction cosine, for each ray
RMAX	-	defined in ARRAY
IMAX	-	defined in ARRAY
JMAX	-	defined in ARRAY
TOL	-	if the direction cosine of the difference in the direction of the point of interest and a particular coordinate of the window area is greater than TOL then this coordinate is used to obtain the point where the ray passes through the radome surface

f. NORM

```
COMMON FILE (60,90,3),NSEC,ANGI,ANGD,NANG,AX,AY,AZ
COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN
COMMON/BLK5/NSTART,NFIN
COMMON/BLK6/IFILE(45,45),JFILE(45,45)
COMMON/BLK13/IMAX,JMAX
DIMENSION FILEEN(45,45,3)
EQUIVALENCE (EFILE,FILEN)
COMMON/BLK10/LT
DATA BN/   /
DATA B1/   /
      .
      .
      .
DATA B6/   /
```

FILE	-	defined in SFILE
NSEC	-	"
ANGI	-	"
ANGD	-	"
NANG	-	"
AX	-	"
AY	-	"
AZ	-	"
NUMM	-	defined in ARRAY
NUMN	-	"
NSTART	-	defined in START

NFIN	-	defined in START
IFILE	-	defined in DIRER
JFILE	-	"

g. INCID

```
COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN
COMMON/BLK4/XY(200),XZ(200)
DIMENSION FILEN(45,45,3)
EQUIVALENCE(EFILE,FILEN)
COMMON/BLK8/FILEE(45,45,3)
COMMON/BLK9/XINCID(45,45)
COMMON/BLK10/LT
COMMON/BLK13/IMAX,JMAX
```

EFILE,NUMM,NUMN	-	defined in ARRAY
XY,XZ	-	defined in SFILE
IFILE,JFILE	-	defined in DIRER
FINEN	-	defined in NORM
EFILE	-	defined in ARRAY
FILEE	-	defined in DIRER
XINCID	-	file of incidence angles for each ray passing through the radome wall
LT	-	defined in NORM
IMAX,JMAX	-	defined in ARRAY
IMAX	-	defined in ARRAY
JMAX	-	defined in ARRAY

FILEN	-	file of normals for ray/radome intersection, for those rays passing through the radome wall (in antenna coordinates)
LT	-	used to test the value of IFILE in DIRER
EFILE	-	defined in ARRAY

BN
B1
B2
B3
B4
B5
B6

coefficients of six-degree polynomial fit of radome's outside mold line contour

SECTION IV
MAIN PROGRAM INPUT

The input deck structure is shown in Figure 8.

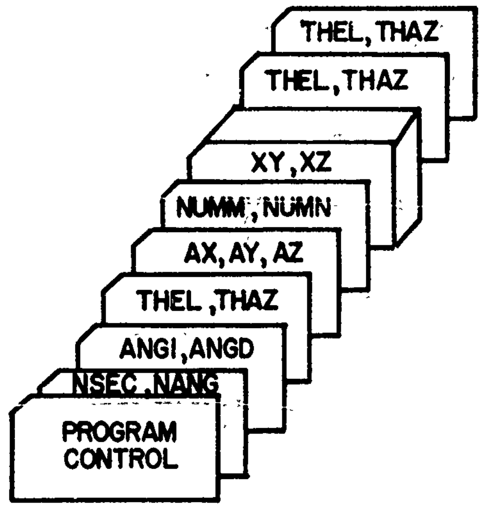

Figure 8. Input Deck Structure

Data Definitions are as follows:

VARIABLE	-	DESCRIPTION	FORMAT
NSEC	-	number of radome stations	2I5
NANG	-	number of circumferential radome divisions	2I5
ANGI	-	initial rotation angle in degrees	2F10.5
ANGD	-	angular increment	
THEL	-	antenna elevation scan angle in degrees	2F10.4
THAZ	-	antenna azimith scan angle in degrees	
AX,AY,AZ	-	radome coordinates of antenna phase center	3F10.4

NUMM	-	maximum allowable antenna row number	2I2
NUMN	-	maximum allowable antenna column number	
XY,XZ	-	radome contour coordinates in radome coordinates	2F10.4

SECTION V

USER'S GUIDE

1. PROGRAM CONTROL

To use the radome analysis program for a given problem, the user must set up the input deck and control cards.

A sample problem is presented in this section. Also shown is how specific sections of that problem are related to the sample input. The printed output of the sample program is included.

The following control card deck structure is presented as a guide to the user. The control card structure is applicable to CDC 6600 CYBER 74 SCOPE 3.4.1.

The radome program has been previously stored on a permanent file. The ATTACH card requests the program. A LABEL card is used to make available a magnetic tape for data storage. The data is first written onto a permanent file that has been requested by a REQUEST card. The source decks are transferred to a program library by the UPDATE card. The program is then compiled (FTN), loaded (LGO), and finally cataloged. The cataloged file is rewound and then copied to magnetic tape (Figure 9a).

On subsequent runs there is a difference in the control cards to allow extending the data on the magnetic tape. The radome program is attached along with the permanent file containing the old data. The

tape label is read and the program transferred to the library file by the UPDATE card. The first set of information on the permanent file is skipped, the program compiled, loaded, and executed. The data on the permanent file is extended, the file rewound, and then the entire file copied onto magnetic tape (Figure 9b).

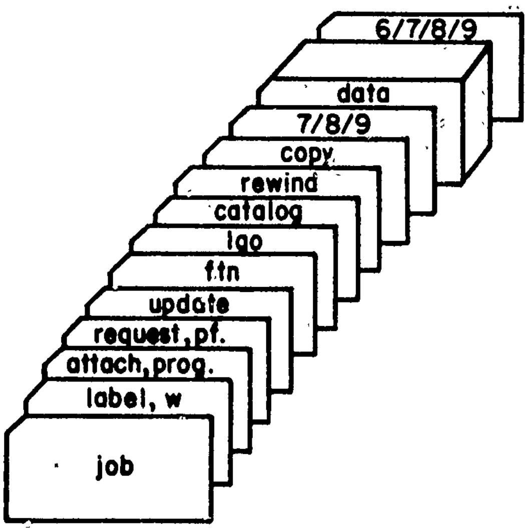

Figure 9a. First Update Deck in Program Control

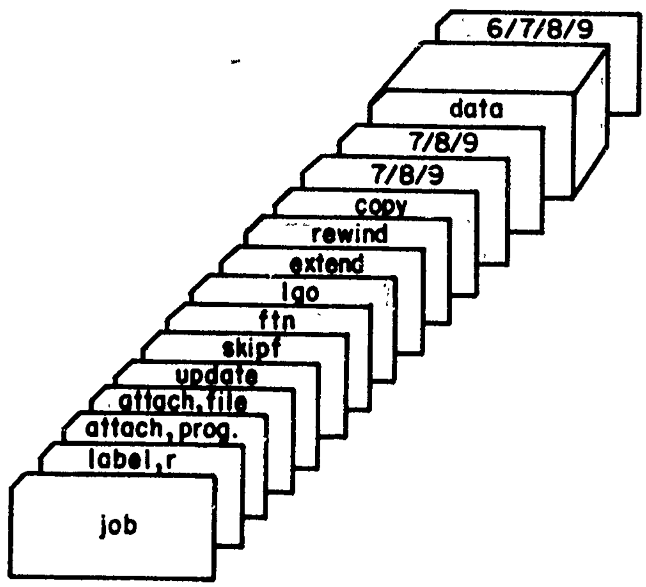

Figure 9b. Second Update Deck in Program Control

2. SAMPLE PROBLEM

A cut is to be made in the azimuth plane. The first step consists of using the Main Program routine, in which the following variable values are used:

1. Number of radome stations equals 117 (NSEC=117)
2. Initial rotation angle equals 0.0 (ANGI=0.0)
3. Number of angular intervals about radome equals 90 (NANG=90)
4. Angular interval equals -4.0 degrees (ANGD=-4.0)

The number of computer runs, i.e., sets of azimuth and elevation scan angles has been set at 3 (NRUN=3). Elevation, and azimuth scan angles (THEL,THAZ) are inputs, one set per card, three cards per run.

3. SAMPLE INPUT

Proceeding to the subroutines, we will have inputs as outlined in the following.

a. ARRAY

Wavelength of interest in inches, XLAMDA

DATA XLAMDA/1.2/

Maximum aperture radius in inches, RR

DATA RR/18.0/

Maximum allowable number of rows and columns in the array, respectively (45,45)

NUMM = 45

NUMN = 45

b. SFILE

Coordinates of the radome contour for radome station I=1, 117

XY(1) = Y1

XZ(1) = Z1

.

.

.

.

.

XY(117) = Y117

XZ(117) = Z117

c. Data Input Format

Card No.	Variable(s)	Format
1	NSEC,NANG	2I5
2	ANGI,ANGD	2F10.5
3	THEL,THAZ	2F10.5
4	AX,AY,AZ	3F10.4

5	NUMM,NUMN	2I2
6-122	XY(I),XZ(I)	2F10.4
123	THEL,THAZ	2F10.5
124	THEL,THAZ	2F10.5

d. The steps given in Section V are shown as flowcharts in Figures 10, 11, and 12. Final printout from our example problem follow the flowcharts.

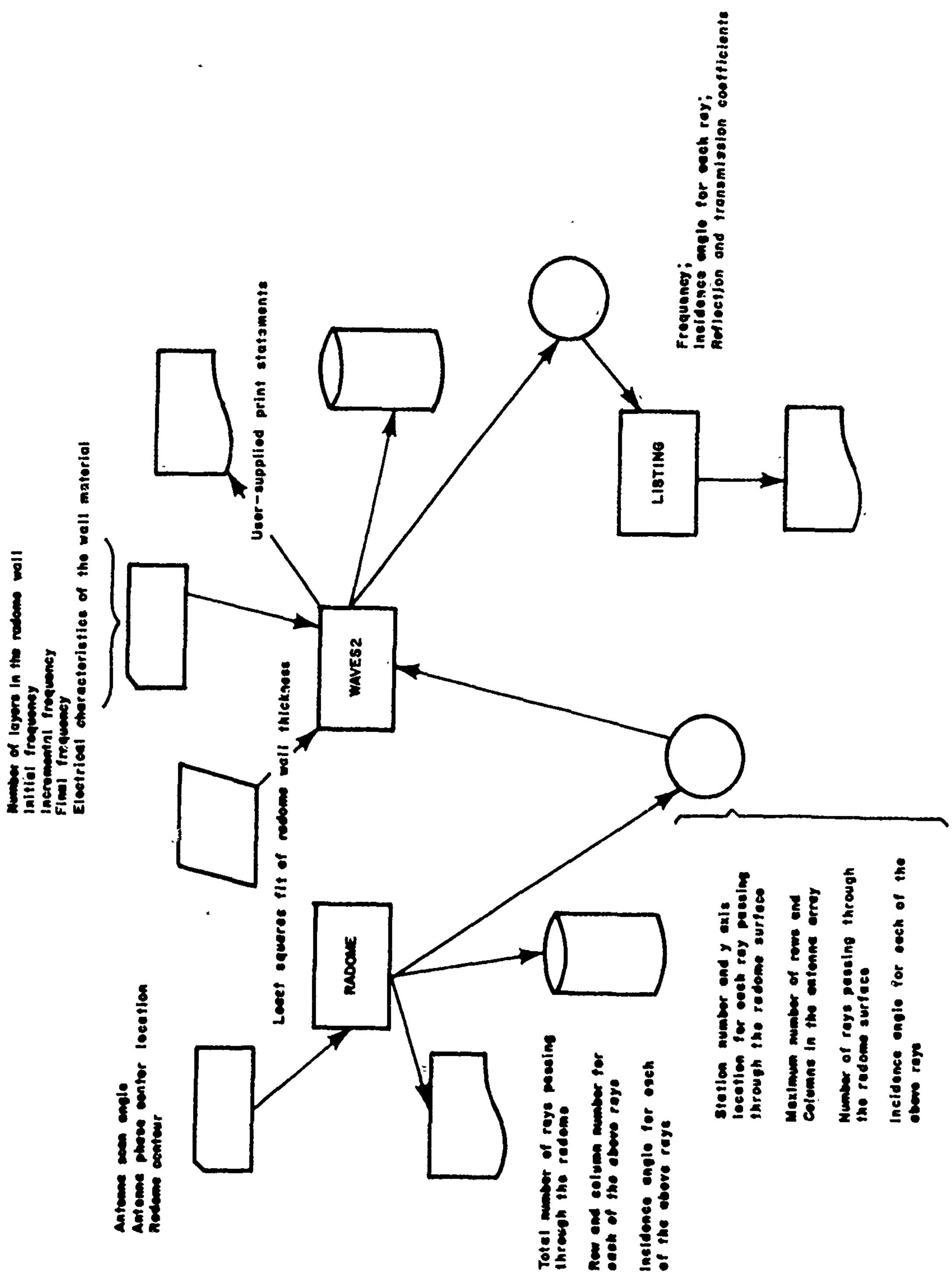

Figure 10. System Flow Chart.

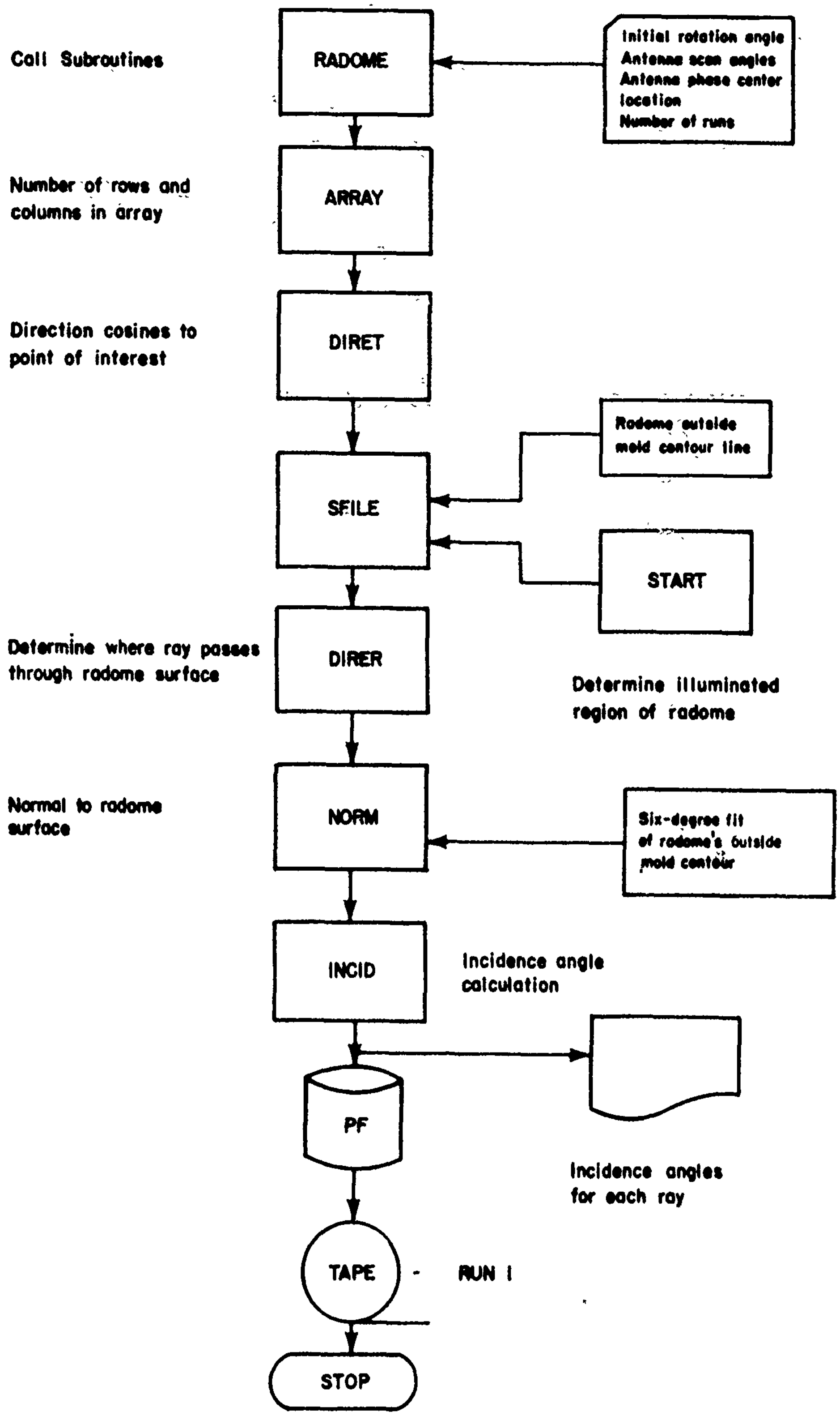

Figure 11. Radome-Geometry Program Flow Chart

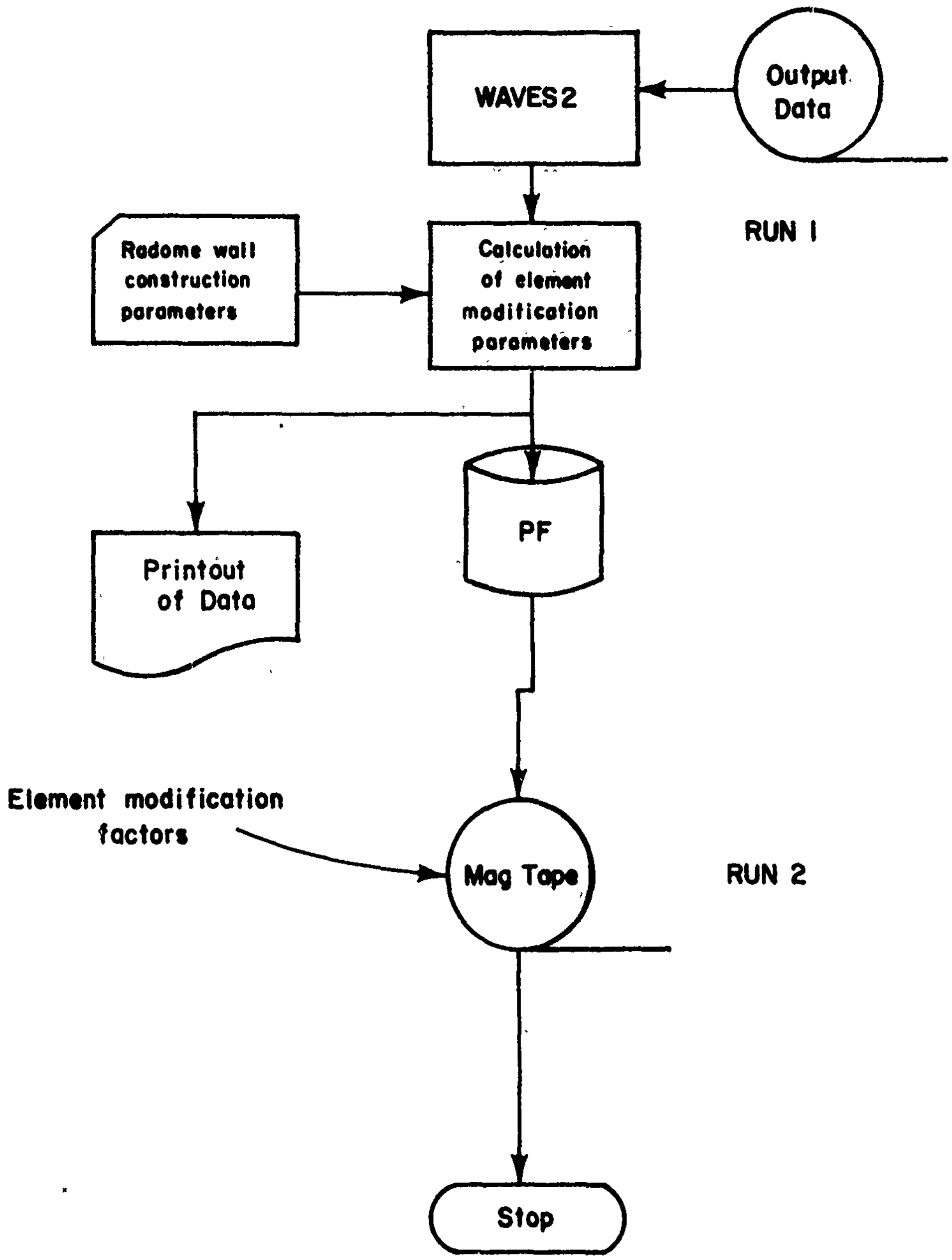

Figure 12. WAVES2 Program Flow Chart

4. SAMPLE OUTPUT

```
PROGRAM RADOME     74/74   OPT=2                                    FTN 4.2+P380     03/27/75  11.06.06.      PAGE

         PROGRAM RADOME(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)          RADOME    2
         COMMON FILE(45,45,3),NSEC,ANGI,ANGD,NANG,AX,AY,AZ                    RADOME    3
         COMMON/BLK1/TGTX,TGTY,TGTZ                                           RADOME    4
         COMMON/BLK3/ARGET(45,45,3)                                           RADOME    5
         COMMON/BLK20/SW2                                                     RADOME    6
C READ INPUT PARAMETERS                                                        RADOME    7
C NSEC=TOTAL NUMBER OF RADOME SECTIONS                                         RADOME    8
C ANGI= INITIAL ROTATION ANGLE                                                 RADOME    9
C ANGD=INCREMENTAL ANGLE ROTATION                                              RADOME   10
C NANG= NUMBER OF ANGULAR  POSITIONS                                           RADOME   11
C R,THEL,THAZ ARE TGT RANGE,EL AND AZ ANGLES                                   RADOME   12
C AX,AY,AZ ARE THE ANTENNA PHASE CENTER LOCATIONS IN RADOME COORDINATES        RADOME   13
C                                                                              RADOME   14
      LOGICAL SW2                                                              RADOME   15
      NRUN=0                                                                   RADOME   16
      SW2=.TRUE.                                                               RADOME   17
      READ (5,100)NSEC,NANG                                                    RADOME   19
  100 FORMAT(2I5)                                                              RADOME   20
      READ(5,200)ANGI,ANGD                                                     RADOME   21
  200 FORMAT(2F10.5)                                                           RADOME   22
    1 CONTINUE                                                                 RADOME   23
      NRUN=NRUN+1                                                              RADOME   24
      READ(5,210)THEL,THAZ                                                     RADOME   25
  210 FORMAT(2F10.4)                                                           RADOME   26
      R=1.E+06                                                                 RADOME   27
      WRITE(7)THEL,THAZ                                                        RADOME   28
      PRINT(6,130)NSEC,NANG,ANGI,ANGD,R,THEL,THAZ                              RADOME   29
  130 FORMAT(1H0,*NSEC=*,I3,2X,*NANG=*,I3,2X,*ANGI=*,                          RADOME   30
     1F10.4,2X,*ANGD=*,F10.4,2X,*R=*,F10.2,2X,*THEL=*,F10.4,2X,                RADOME   31
     1*THAZ=*,F10.4)                                                           RADOME   32
      IF(.NOT.SW2) GO TO 141                                                   RADOME   33
      READ(5,110)AX,AY,AZ                                                      RADOME   34
  110 FORMAT(3F10.4)                                                           RADOME   35
  141 CONTINUE                                                                 RADOME   36
      PRINT  140                                                               RADOME   37
  140 FORMAT(1X,/1X,*      AX          AY          AZ        *)                RADOME   38
      PRINT(6,150)AX,AY,AZ                                                     RADOME   39
  150 FORMAT(3F10.4)                                                           RADOME   40
C     COMPUTE TGT LOCATION IN ANTENNA COORDINATES                              RADOME   41
      THELR=THEL*(3.14159/180.)                                                RADOME   42
      THAZR=THAZ*(3.14159/180.)                                                RADOME   43
      TGTX=R*COS(THELR)*SIN(THAZR)                                             RADOME   44
      TGTY=R*COS(THELR)*COS(THAZR)                                             RADOME   45
      TGTZ=R*SIN(THELR)                                                        RADOME   46
      PRINT(6,160)TGTX,TGTY,TGTZ                                               RADOME   47
  160 FORMAT(1X,*  TGTX=*,E10.4,*. TGTY=*,E10.4,*  TGTZ=*,E10.4)               RADOME   48
C     INPUT ANTENNA ELEMENT SPACING IN ANTENNA COORDINATES                     RADOME   52
      CALL ARRAY                                                               RADOME   53
      CALL DIRET                                                               RADOME   54
C SUBROUTINE SFILE GENERATES THE XYZ COORDINATES OF THE SURFACE IN ANT.        RADOME   55
      CALL SFILE                                                               RADOME   56
      CALL DIREP                                                               RADOME   57
      CALL NORM                                                                RADOME   58
      CALL INCID                                                               RADOME   59
      SW2=.FALSE.                                                              RADOME   60
      IF(NRUN.NE.3) GO TO 1                                                    RADOME   61
      STOP                                                                     RADOME   62
```

```
SUBROUTINE ARRAY       74/74    OPT=2                          FTN 4.2+P380        03/27/75  11.05.08.        PAGE

      SUBROUTINE ARRAY
      COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN
      COMMON/BLK12/RMAX
      COMMON/BLK13/IMAX,JMAX
      COMMON/BLK20/SW2
      LOGICAL SW2
      DATA XLAMDA/1.20/
      DATA RR/18.0/
      RMAX=RR
      IF(.NOT.SW2) GO TO 101
      READ(5,100)NUMM,NUMN
  100 FORMAT(2I2)
  101 CONTINUE
      PRINT(6,110)NUMM,NUMN
  110 FORMAT(1H0,*NUMM=*,I2,*NUMN=*,I2)
      PRINT(6,800)RMAX,XLAMDA
  800 FORMAT(1H0,*RMAX=*,F11.3,*XLAMDA=*,F11.5)
      XX=XLAMDA/4.
      DO 120 II=2,NUMM,2
      IF(XX.GT.RMAX) GO TO 130
      XX=XX+XLAMDA/2.
  120 CONTINUE
  130 IMAX=II-2
      JMAX=II-2
      PRINT (6,600)IMAX,JMAX
  600 FORMAT(1H0,*IMAX=*,I2,*JMAX=*,I2)
      DO 1000 I=1,IMAX
      DO 1001 J=1,JMAX
      EFILE(I,J,1)=1000.
      EFILE(I,J,2)=1000.
      EFILE(I,J,3)=1000.
 1001 CONTINUE
 1000 CONTINUE
      XX=XLAMDA/4.
      XZ=XLAMDA/4.
      L=0
      DO 140 I=2,IMAX,2
      DO 150 J=2,JMAX,2
      EFILE(I,J,1)=XX
      EFILE(I,J,2)=0.0
      EFILE(I,J,3)=XZ
      X=EFILE(I,J,1)
      Y=EFILE(I,J,2)
      Z=EFILE(I,J,3)
      R=SQRT(X**2+Z**2)
      IF(R.GT.RMAX) GO TO 170
      XX=XX+(XLAMDA/2.)
      L=L+1
  150 CONTINUE
  170 XZ=XZ+(XLAMDA/2.)
      XX=XLAMDA/4.
  140 CONTINUE
      LL=4*L
      PRINT(6,900)LL
  900 FORMAT(1H0,*TOTAL NUMBER OF ELEMENTS =*,I4)
C     DO UPPER RIGHT QUAD.
      JMAX=JMAX-1
```

```
SUBROUTINE ARRAY      74/74   OPT=2                    FTN 4.2+P380      05/27/75  11.05.08.       PAGE

                 DO 200 I=2,IMAX,2                                                ARRAY      60
                 DO 210 J=1,JMAX,2                                                ARRAY      61
 60              EFILE(I,J,1)=-EFILE(I,J+1,1)                                     ARRAY      62
                 EFILE(I,J,2)=0.0                                                 ARRAY      63
                 EFILE(I,J,3)=EFILE(I,J+1,3)                                      ARRAY      64
           210   CONTINUE                                                         ARRAY      65
           200   CONTINUE                                                         ARRAY      66
 65        C     DO LOWER LEFT QUAD                                               ARRAY      67
                 JMAX=JMAX+1                                                      ARRAY      68
                 IMAX=IMAX-1                                                      ARRAY      69
                 DO 300 I=1,IMAX,2                                                ARRAY      70
                 DO 310 J=2,JMAX,2                                                ARRAY      71
 70              EFILE(I,J,1)=EFILE(I+1,J,1)                                      ARRAY      72
                 EFILE(I,J,2)=0.0                                                 ARRAY      73
                 EFILE(I,J,3)=-EFILE(I+1,J,3)                                     ARRAY      74
           310   CONTINUE                                                         ARRAY      75
           300   CONTINUE                                                         ARRAY      76
 75        C     DO LOWER RIGHT QUAD.                                             ARRAY      77
                 JMAX=JMAX-1                                                      ARRAY      78
                 DO 400 I=1,IMAX,2                                                ARRAY      79
                 DO 410 J=1,JMAX,2                                                ARRAY      80
                 EFILE(I,J,1)=-EFILE(I,J+1,1)                                     ARRAY      81
 80              EFILE(I,J,2)=0.0                                                 ARRAY      82
                 EFILE(I,J,3)=EFILE(I,J+1,3)                                      ARRAY      83
           410   CONTINUE                                                         ARRAY      84
           400   CONTINUE                                                         ARRAY      85
                 IMAX=IMAX+1                                                      ARRAY      86
 85              JMAX=JMAX+1                                                      ARRAY      87
                 DO 500 I=1,IMAX,5                                                ARRAY      88
                 DO 510 J=1,JMAX,5                                                ARRAY      89
                 X1=EFILE(I,J,1)                                                  ARRAY      90
                 Z1=EFILE(I,J,3)                                                  ARRAY      91
 90              R1=SQRT(X1**2+Z1**2)                                             ARRAY      92
                 IF(R1.GT.RMAX) GO TO 500                                         ARRAY      93
                 PRINT(6,700)I,J,EFILE(I,J,1),EFILE(I,J,2),EFILE(I,J,3)           ARRAY      94
           700   FORMAT(1H0,1X,I2,3X,I2,3F11.5)                                   ARRAY      95
           510   CONTINUE                                                         ARRAY      96
 95        500   CONTINUE                                                         ARRAY      97
                 RETURN                                                           ARRAY     101
                 END                                                              ARRAY     102

REGISTER ALLOCATION
1. REGISTERS ASSIGNED OVER THE LOOP BEGINNING AT LINE 28
```

```
SUBROUTINE DIRET       74/74   OPT=2                   FTN 4.2+P380      03/27/75  11.06.15.     PAGE

               SUBROUTINE DIRET                                              DIRET      2
               COMMON/BLK1/TGTX,TGTY,TGTZ                                    DIRET      3
               COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN                          DIRET      4
               COMMON/BLK3/ABGET(45,45,3)                                    DIRET      5
               COMMON/BLK12/RMAX                                             DIRET      6
               COMMON/BLK13/IMAX,JMAX                                        DIRET      7
       C     * THIS SUBROUTINE CALCULATES THE DIRECTION COSINES FROM EACH    DIRET      8
       C       ELEMENT TO THE TARGET                                         DIRET      9
               PRINT 130                                                     DIRET     11
         130   FORMAT(1X,/1X,*  DIRECTION COSINES FROM I,J, ELEMENT TO TGT  */)  DIRET  12
               DO 100 I=1,IMAX                                               DIRET     13
               DO 110 J=1,JMAX                                               DIRET     14
               X=EFILE(I,J,1)                                                DIRET     15
               Z=EFILE(I,J,3)                                                DIRET     16
               R=SQRT(X**2+Z**2)                                             DIRET     17
               IF(R.GT.RMAX) GO TO 100                                       DIRET     18
               XTX=TGTX-EFILE(I,J,1)                                         DIRET     19
               XTY=TGTY-EFILE(I,J,2)                                         DIRET     20
               XTZ=TGTZ-EFILE(I,J,3)                                         DIRET     21
               XMAG=SQRT(XTX**2+XTY**2+XTZ**2)                               DIRET     22
               ABGET(I,J,1)=XTX/XMAG                                         DIRET     23
               ABGET(I,J,2)=XTY/XMAG                                         DIRET     24
               ABGET(I,J,3)=XTZ/XMAG                                         DIRET     25
         110   CONTINUE                                                      DIRET     26
         100   CONTINUE                                                      DIRET     27
               DO 300 I=1,IMAX,5                                             DIRET     28
               DO 400 J=1,JMAX,5                                             DIRET     29
               X1=EFILE(I,J,1)                                               DIRET     30
               Z1=EFILE(I,J,3)                                               DIRET     31
               R1=SQRT(X1**2+Z1**2)                                          DIRET     32
               IF(R1.GT.RMAX) GO TO 300                                      DIRET     33
               PRINT(6,120)I,J,ABGET(I,J,1),ABGET(I,J,2),ABGET(I,J,3)        DIRET     34
         120   FORMAT(1X,/1X,*  ABGET(*,2I2,*)=*,1X,F10.4,3X,F10.4,3X,F10.4)  DIRET    35
         400   CONTINUE                                                      DIRET     36
         300   CONTINUE                                                      DIRET     37
               RETURN                                                        DIRET     41
               END                                                           DIRET     42
```

```
SUBROUTINE SFILE        74/74    OPT=2                       FTN 4.2+P380        03/27/75  11.06.19.        PAGE

              SUBROUTINE SFILE                                                  SFILE    2
              COMMON FILE(60,90,3),NSEC,ANGI,ANGO,NANG,AX,AY,AZ                 SFILE    3
              COMMON/BLK4/XY(200),XZ(200)                                       SFILE    4
              COMMON/BLK5/NSTART,NFIN                                           SFILE    5
              COMMON/BLK20/SW2                                                  SFILE    6
              DIMENSION FX(90),FY(90),FZ(90)                                    SFILE    7
        C READ CONTOUR LINE XYZ                                                 SFILE    8
              LOGICAL SW2                                                       SFILE    9
              IF(.NOT.SW2) GO TO 101                                            SFILE   11
              DO 100 I=1,NSEC                                                   SFILE   12
              READ(5,110)XY(I),XZ(I)                                            SFILE   13
          110 FORMAT(2F10.4)                                                    SFILE   14
          100 CONTINUE                                                          SFILE   15
          101 CONTINUE                                                          SFILE   16
              CALL START                                                        SFILE   17
        C GENERATE IN RADOME COORDINATES,SURFACE XYZ                            SFILE   18
              ANGII=ANGI                                                        SFILE   19
              L=1                                                               SFILE   20
              DO 120 I=NSTART,NFIN                                              SFILE   21
              DO 130 J=1,NANG                                                   SFILE   22
              ANGR=ANGII*(3.14159/180.)                                         SFILE   23
              FZ(J)=XZ(I)*COS(ANGR)                                             SFILE   24
              FX(J)=XZ(I)*SIN(ANGR)                                             SFILE   25
              FILE(L,J,1)=FX(J)                                                 SFILE   26
              FILE(L,J,2)=XY(I)                                                 SFILE   27
              FILE(L,J,3)=FZ(J)                                                 SFILE   28
              ANGII=ANGII+ANGO                                                  SFILE   29
          130 CONTINUE                                                          SFILE   30
              ANGII=ANGI                                                        SFILE   31
              L=L+1                                                             SFILE   32
          120 CONTINUE                                                          SFILE   33
              DO 200 I=1,60,10                                                  SFILE   34
              DO 210 J=1,90,10                                                  SFILE   35
              PRINT (6,300) FILE(I,J,1),FILE(I,J,2),FILE(I,J,3)                 SFILE   36
          300 FORMAT(1X,3E10.4)                                                 SFILE   37
          210 CONTINUE                                                          SFILE   38
          200 CONTINUE                                                          SFILE   39
        C TRANSFORM THE DATA TO ANTENNA COORDINATES                             SFILE   40
              DO 150 I=1,60                                                     SFILE   41
              DO 140 J=1,NANG                                                   SFILE   42
              FILE(I,J,1)=-(FILE(I,J,1)-AX)                                     SFILE   43
              FILE(I,J,2)=AY-FILE(I,J,2)                                        SFILE   44
              FILE(I,J,3)=FILE(I,J,3)-AZ                                        SFILE   45
          140 CONTINUE                                                          SFILE   46
          150 CONTINUE                                                          SFILE   47
              PRINT 450                                                         SFILE   48
          450 FORMAT(1X,/1X,*    XYZ OF SURFACE IN ANTENNA COORDINATES     *)   SFILE   49
              DO 320 I=1,60,5                                                   SFILE   50
              DO 310 J=1,90,10                                                  SFILE   51
              TX=FILE(I,J,1)                                                    SFILE   52
              TY=FILE(I,J,2)                                                    SFILE   53
              TZ=FILE(I,J,3)                                                    SFILE   54
              TMAG=SQRT(TX**2+TY**2+TZ**2)                                      SFILE   55
              A=TX/TMAG                                                         SFILE   56
              B=TY/TMAG                                                         SFILE   57
              G=TZ/TMAG                                                         SFILE   58
              PRINT(6,400)FILE(I,J,1),FILE(I,J,2),FILE(I,J,3),A,B,G             SFILE   59
```

```
SUBROUTINE SFILE       74/74    OPT=2                        FTN 4.2+P380       03/27/75  11.06.19.       PAGE

           400  FORMAT(1X,3F10.4,3X,3F10.5)                                      SFILE      60
           310  CONTINUE                                                          SFILE      61
           320  CONTINUE                                                          SFILE      62
                RETURN                                                            SFILE      66
                END                                                               SFILE      67

REGISTER ALLOCATION
3 REGISTERS ASSIGNED OVER THE LOOP BEGINNING AT LINE 40
```

```
SUBROUTINE START      74/74   OPT=2                    FTN 4.2+P380      03/27/75  11.06.22.       PAGE

              SUBROUTINE START                                                START      2
      C       THIS SUBROUTINE DETERMINES THE GENERAL PEGION TO BEGIN THESEARCH START      3
              COMMON FILE(60,90,3),NSEC,ANGI,ANGD,NANG,AX,AY,AZ               START      4
              COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN                            START      5
              COMMON/BLK3/ABGET(45,45,3)                                      START      6
              COMMON/BLK4/XY(200),XZ(200)                                     START      7
              COMMON/BLK5/NSTART,NFIN                                         START      8
              A=ACOS(ABGET(2,2,2))                                            START     10
              PRINT(6,200)ABGET(2,2,2)                                        START     11
         200  FORMAT(1H0,*ABGET=*,F11.5)                                      START     12
              DO 100 I=1,NSEC                                                 START     13
              XYX=AY-XY(I)                                                    START     14
              Z=XYX*TAN(A)                                                    START     15
              IF(Z.LT.XZ(I))GO TO 110                                         START     16
         100  CONTINUE                                                        START     17
         110  NSTART=I                                                        START     18
              PRINT(6,210)I                                                   START     19
         210  FORMAT(1H0,*I=*,I3)                                             START     20
              DO 130 J=1,30                                                   START     21
              NSTART=NSTART-1                                                 START     22
              IF(NSTART.LT.1)GO TO 140                                        START     23
         130  CONTINUE                                                        START     24
              NFIN=NSTART+59                                                  START     25
              IF(NFIN.LT.NSEC) GO TO 150                                      START     26
              NFIN=NSEC                                                       START     27
              NSTART=NSEC-59                                                  START     28
              GO TO 150                                                       START     29
         140  NSTART=NSTART+1                                                 START     30
              NFIN=NSTART+59                                                  START     31
         150  CONTINUE                                                        START     32
              PRINT(6,120)NSTART,NFIN                                         START     33
         120  FORMAT(1X/1X,*NSTART=*,I3,*NFIN=*,I3)                           START     34
              RETURN                                                          START     38
              END                                                             START     39
```

SUBROUTINE DIRER 74/74 OPT=2 FTN 4.2+P380 03/27/75 11.05.24. PAGE

```
      SUBROUTINE DIRER
C
C     THIS SUBROUTINE CALCULATES THE DIRECTION COSINES FROM EACH
C     ELEMENT TO THE SURFACE AND COMPARES THIS NUMBER TO
C     THAT OF THE GIVEN ELEMENT TO THE TGT
      COMMON FILE(60,90,3),NSEC,ANGI,ANGO,NANG,AX,AY,AZ
      COMMON/BLK2/EFILE(45,45,3),NUMM,NUMN
      COMMON/BLK3/ABGET(45,45,3)
      COMMON/BLK5/NSTART,NFIN
      COMMON/BLK6/IFILE(45,45),JFILE(45,45)
      COMMON/BLK8/FILEE(45,45,3)
      COMMON /BLK12/RMAX
      COMMON /BLK13/IMAX,JMAX
      DATA TOL/.99939/
      CALL SECOND(T1)
      PRINT(6,180) TOL
  180 FORMAT(1H0,* TOL = *,F10.6)
      L=0
      DO 100 M=1,IMAX
      DO 110 N=1,JMAX
      X=EFILE(M,N,1)
      Z=EFILE(M,N,3)
      R=SQRT(X**2+Z**2)
      IF(R.GT.RMAX) IFILE(M,N)=1000
      IF(R.GT.RMAX)GO TO 110
      DO 120 I=1,60
      DO 130 J=1,NANG
      ESX=FILE(I,J,1)-EFILE(M,N,1)
      ESY=FILE(I,J,2)-EFILE(M,N,2)
      ESZ=FILE(I,J,3)-EFILE(M,N,3)
      XMAGES=SQRT(ESX**2+ESY**2+ESZ**2)
      ALPHA=ESX/XMAGES
      BETTA=ESY/XMAGES
      GAMMA=ESZ/XMAGES
      FILEE(M,N,1)=ALPHA
      FILEE(M,N,2)=BETTA
      FILEE(M,N,3)=GAMMA
      DC=ABGET(M,N,1)*ALPHA+ABGET(M,N,2)*BETTA+ABGET(M,N,3)*GAMMA
      IF(DC .LT. TOL ) GO TO 170
      II=NSTART+I-1
      L=L+1
      LL=MOD(L,5)
      IF(LL.NE.0)GO TO 500
  140 PRINT(6,160)M,N,II,J,DC
  160 FORMAT(1H0,* RAY(*,I2,*,*,I2,*) INTERSECTS SECTION(*,I3,*,*,I3,
     1*) DC= *,F8.5)
  500 IFILE(M,N)=II
      JFILE(M,N)=J
      GO TO 110
  170 CONTINUE
C     THIS IS A TEST FOR INTERSECTION WITH THE SURFACE
      IFILE(M,N)=1000
  130 CONTINUE
  120 CONTINUE
      PRINT (6,150)M,N,TOL
  150 FORMAT(1X,*RAY(*,I2,*,*,I2,*)DOES NOT INTERSECT WITH THE SURF.
     1GIVEN TOL  *,F11.5)
```

```
      SUBROUTINE DIRER       74/74    OPT=2                          FTN 4.2+P380        03/27/75  11.06.24.        PAGE

           110  CONTINUE                                                  DIRER       59
           100  CONTINUE                                                  DIRER       60
 60             CALL SECOND(T2)                                           DIRER       61
                DELT=T2-T1                                                DIRER       62
                PRINT*,DELT                                               DIRER       63
                RETURN                                                    DIRER       64
                END                                                       DIRER       65
```

```
SUBROUTINE NORM       74/74    OPT=?                    FTN 4.2+P380     03/22/75  11.05.29;       PAGE

          SUBROUTINE NORM                                                NORM      2
          COMMON FILE(45,31,3),NSEC,ANGI,ANGD,NANG,AX,AY,AZ              NORM      3
          COMMON/BLK2/ FILF(45,45,3),NUMM,NUMN                           NORM      4
          COMMON/BLK5/NSTART,NFIN                                        NORM      5
          COMMON/BLK6/IFILE(45,45),JFILE(45,45)                          NORM      6
          COMMON/BLK13/IMAX,JMAX                                         NORM      7
          DIMENSION FILEN(45,45,3)                                       NORM      8
          EQUIVALENCE (EFILE,FILEN)                                      NORM      9
          COMMON/BLK10/LT                                                NORM     10
          DATA B0/-.51754939E-01/                                        NORM     11
          DATA B1/.34291929E+00/                                         NORM     12
          DATA B2/-.17442715E-02/                                        NORM     13
          DATA B3/.23997697E-04/                                         NORM     14
          DATA B4/0.0/                                                   NORM     15
          DATA B5/-.25443686E-08/                                        NORM     16
          DATA B6/.12667666E-10/                                         NORM     17
          PRINT 200                                                      NORM     19
  200     FORMAT(1H0,*  X,Y,Z    IN RADOME COORD. AND F(Y) *)            NORM     20
          K=0                                                            NORM     21
          DO 100 M=1,IMAX                                                NORM     22
          DO 110 N=1,JMAX                                                NORM     23
          LT=998                                                         NORM     24
          IF(IFILE(M,N).GT.LT) GO TO 110                                 NORM     25
          I=IFILE(M,N)                                                   NORM     26
          I=I-NSTART+1                                                   NORM     27
          J=JFILE(M,N)                                                   NORM     28
C         THE ORIGINAL CURVEFIT WAS DONE IN RADOME COORDINATES           NORM     29
          XX=-FILE(I,J,1)+AX                                             NORM     30
          XY=AY-FILE(I,J,2)                                              NORM     31
          XZ=FILE(I,J,3)+AZ                                              NORM     32
          XY1=XY                                                         NORM     33
          XY2=XY**2                                                      NORM     34
          XY3=XY**3                                                      NORM     35
          XY4=XY**4                                                      NORM     36
          XY5=XY**5                                                      NORM     37
          XY6=XY**6                                                      NORM     38
          F=B0+B1*XY1+B2*XY2+B3*XY3+B4*XY4+B5*XY5+B6*XY6                 NORM     39
          K=K+1                                                          NORM     40
          KK=MOD(K,10)                                                   NORM     41
          IF(KK.NE.0) GO TO 131                                          NORM     42
          PRINT(6,130)XX,XY,XZ,F                                         NORM     43
  130     FORMAT(1H0,4F10.5)                                             NORM     44
  131     DFY=B1+2*B2*XY1+3*B3*XY2+4*B4*XY3+5*B5*XY4+6*B6*XY5            NORM     45
          XNX=XX                                                         NORM     46
          XNZ=XZ                                                         NORM     47
          XNY=-F*DFY                                                     NORM     48
          XMAGN=SQRT(XNX**2+XNY**2+XNZ**2)                               NORM     49
          XAN=XNX/XMAGN                                                  NORM     50
          XBN=XNY/XMAGN                                                  NORM     51
C         TRANSFORM THE DATA TO ANT. COORD.                              NORM     52
          XAN=-XAN                                                       NORM     53
          XBN=-XBN                                                       NORM     54
          XGN=XNZ/XMAGN                                                  NORM     55
C         FILEN CONTAINS THE DIRECTION COSINES OF THE NORMALS FOR EL M,N NORM     56
          FILEN(M,N,1)=XAN                                               NORM     57
          FILEN(M,N,2)=XBN                                               NORM     58
          FILEN(M,N,3)=XGN                                               NORM     59
```

```
SUBROUTINE NORM        74/74    OPT=2                    FTN 4.2+P380       03/27/75  11.06.29        PAGE

        110  CONTINUF
        100  CONTINUF
             PRINT 140
        140  FORMAT(1H0,*FILE OF DIRECTION COSINES FOR NORMAL OF EL. M,N*,/)
             K1=0
             DO 150 M=1,IMAX
             DO 160 N=1,JMAX
             IF(IFILF(M,N).GT.LT) GO TO 160
             K1=K1+1
             K2=MOD(K1,10)
             IF(K2.GT.0) GO TO 160
             PRINT(6,170)M,N,FILEN(M,N,1),FILEN(M,N,2),FILEN(M,N,3)
        170  FORMAT(1X,*ELEMENT(*,I2,*,*,I2,*)  *,3E11.5)
        160  CONTINUE
        150  CONTINUE
             RETURN
             END
```

```
SUBROUTINE INCID       74/74    OPT=2                          FTN 4.2+P380        03/27/75  11.07.38.        PAGE

                SUBROUTINE INCID                                                  INCID        2
                COMMON/BLK2/FFILE(45,45,3),NUMM,NUMN                              INCID        3
                COMMON/BLK4/XY(200),XZ(200)                                       INCID        4
                COMMON/BLK6/IFILE(45,45),JFILE(45,45)                             INCID        5
                DIMENSION FILEN(45,45,3)                                          INCID        6
                EQUIVALENCE (EFILE,FILEN)                                         INCID        7
                COMMON/BLK8/FILEE(45,45,3)                                        INCID        8
                COMMON/BLK9/XINCID(45,45)                                         INCID        9
                COMMON/BLK10/LT                                                   INCID       10
                COMMON/BLK13/IMAX,JMAX                                            INCID       11
          C     FILEN CONTAINS THE DIR COSINES FOR THE NORMAL OF EA. EL.          INCID       12
          C     FILEE CONTAINS THE DIR COSINES FOR THE EL TO RADOME VECTOR        INCID       13
                PRINT 300                                                         INCID       15
            300 FORMAT (1H0,* INCIDENT ANGLE DIRECTION COSINE AND ANGLE (DEG)*)   INCID       15
                K3=0                                                              INCID.      17
                DO 100 M=1,IMAX                                                   INCID       18
                DO 110 N=1,JMAX                                                   INCID       19
                IF(IFILE(M,N).GT.LT)XINCID(M,N)=1000..                            INCID       20
                IF(IFILE(M,N).GT.LT) GO TO 200                                    INCID       21
                XINCID(M,N)=FILEE(M,N,1)*FILEN(M,N,1)+FILEE(M,N,2)*FILEN(M,N,2)+  INCID       22
               1FILEE(M,N,3)*FILEN(M,N,3)                                         INCID       23
                XDEGR=ACOS(XINCID(M,N))                                           INCID       24
                XDEG=XDEGR*(180./3.14159)                                         INCID       25
                K3=K3+1                                                           INCID       26
                K4=MOD(K3,5)                                                      INCID       27
                IF(K4.GT.0) GO TO 200                                             INCID       28
                PRINT(6,120)M,N,XINCID(M,N),XDEG                                  INCID       29.
            120 FORMAT(1H0,*INCID(*,I2,*,*,I2,*)=*,F11.5,1X,E11.5)                INCID       30
            200 CONTINUE                                                          INCID       31
            110 CONTINUE                                                          INCID       32
            100 CONTINUE                                                          INCID       33
                PRINT(6,400)K3                                                    INCID       34
            400 FORMAT(1H0,*NUMBER OF BISTATIC ANGLES =*,I4)                      INCID       35
                WRITE(7)IMAX,JMAX,K3,XINCID,IFILE,XY                              INCID       36
                RETURN                                                            INCID       40
                END                                                               INCID       41
```

SECTION VI
FLAT-PANEL ANALYSIS PROGRAM (WAVES2)

1. ADAPTING THE RADOME PROGRAM

Thus far, the radome analysis program has been one of geometry, i.e., determining the incidence angles for rays passing through the radome wall; there remains the task of determining how the radome wall modifies the electrical parameters of each ray. To accomplish this, first, a flat-panel analysis program (Krueger, AFAL-TR-67-191, Sep 67) is used to calculate the following:

Power reflection coefficient
Electrical angle after reflection
Insertion loss
Insertion phase delay

Our original flat-panel program required input via data cards containing incidence angles and material thickness. But, due to the increasing number of rays considered, input via data cards became prohibitive, and modification of the flat-panel program was required. The program was modified to read the required input data from magnetic tape. Such inputs consisted of the following:

Coefficients of the six-degree polynominal fit of the radome
The radome's outside mold line contour
Maximum number of row and column elements in the array
Incidence angles and their total number
Radome station number where each ray passes through
Coordinate of radome surface where each ray passes through the surface

A printout of these inputs follows.

2. WAVES2 PRINTOUT

```
PROGRAM WAVES2      74/74    OPT=1                              FTN 4.2+P380       03/27/75  18.17.02.        PAGE

      PROGRAM WAVES2(INPUT,OUTPUT,T    5=INPUT,TAPE6=OUTPUT,TAPE8,       WAVES2     2
     1TAPE9,TAPE10)                                                       WAVES2     3
      COMPLEX KM,KE,K,TEZ,THZ,PHI,RTE,RTM,TTE,TTM,IM,THZSC,TEZSC,         WAVES2     4
     1RTESC,RTMSC,TTMSC,TTESC,EMT,EPI,TAN,R1,R2,R3,R4,AE,AM,AES,AMS,CE,C WAVES2     5
     2M,CES,CMS,BE,BM,BES,BMS,PHIK                                        WAVES2     6
      COMPLEX KA(31),KU(31),KE1,KM1,CET,CMT,Y(30),YN,ADMSRD(30),ZN        WAVES2     7
      DIMENSION BETA(2025),THETA(2025),D(20),KM(20,30),KE(20,30),F(       WAVES2     8
     120,30),                                                             WAVES2     9
     1TEZ(30),THZ(30),PHI(30),RTE(30),RTM(30),TTE(30),TTM(30),THZSC(30),  WAVES2    10
     2RTESC(30),RTMSC(30),TTMSC(30),TTESC(30),AE(2,2),AM(2,2),AES(2,2),   WAVES2    11
     3CE(2,2),CM(2,2),CES(2,2),CMS(2,2),BE(2,2),BM(2,2),BES(2,2),BMS(2,2  WAVES2    12
     4),INT(20),MA(20),K(30),TEZSC(30),AMS(2,2),FSTRIP(30)                WAVES2    13
      DIMENSION XINCID(45,45)                                             WAVES2    14
      DIMENSION IFILE(45,45),XY(200),T(2025)                              JAN28      1
      INTEGER CAEXIT                                                      WAVES2    15
      LOGICAL SW1                                                         JAN23      1
      DATA PI/3.141592/                                                   WAVES2    16
      DATA BN/.39476003E+03/                                              JAN23      2
      DATA B2/-.22388918E-02/                                             JAN23      3
      DATA B3/-.16308283E-04/                                             JAN23      4
      SW1=.TRUE.                                                          JAN23      5
  777 CONTINUE                                                            MAR5       1
      JD=0                                                                WAVES2    18
      CAEXIT=0                                                            WAVES2    19
      IM=CMPLX(0.0,1.0)                                                   WAVES2    20
  807 FORMAT(1H1)                                                         WAVES2    22
      READ(8)THEL,THAZ                                                    JAN23      6
      IF(EOF(8).NE.0.)CALL EXIT                                           MAR6       1
      READ(8)IMAX,JMAX,K3,XINCID,IFILE,XY                                 JAN28      2
      WRITE(10)THEL,THAZ                                                  JAN23      7
      WRITE(10)IMAX,JMAX,K3,XINCID                                        WAVES2    29
      PRINT(6,903)THEL,THAZ                                               JAN23      8
  903 FORMAT(1H0,*THEL=*,F10.4,1X,*THAZ=*,F10.4)                          JAN23      9
      MM=0                                                                WAVES2    30
      JJ=K3                                                               FEB4       1
      DO 900 I1=1,IMAX                                                    WAVES2    31
      DO 910 J1=1,JMAX                                                    WAVES2    32
      IF(XINCID(I1,J1).GT.999.) GO TO 910                                 WAVES2    33
      MM=MM+1                                                             WAVES2    34
      BETA(MM)=ACOS(XINCID(I1,J1))                                        WAVES2    35
      BETA(MM)=BETA(MM)*(180./3.14159)                                    WAVES2    36
      T(MM)=XY(IFILE(I1,J1))                                              FEB4       2
  910 CONTINUE                                                            WAVES2    37
  900 CONTINUE                                                            WAVES2    38
      LCNT=0                                                              FEB4       3
  621 CONTINUE                                                            FEB4       4
      LCNT=LCNT+1                                                         FEB4       5
      IF(JD.EQ.JJ)GO TO 777                                               MAR6       2
      IF(.NOT.SW1) GO TO 950                                              FEB4       7
      READ(5,500)NL,NB,FINC,FINT,FFIN                                     FEB4       8
  950 CONTINUE                                                            FEB4       9
      BETA(1)=BETA(LCNT)                                                  FEB4      10
      MA(1)=0                                                             FEB4      11
      MA(2)=0                                                             FEB4      12
      T2=T(LCNT)**2                                                       FEB4      13
      T3=T(LCNT)**3                                                       FEB4      14
      D(1)=(BN+B2*T2+B3*T3)*.001*2.54                                     FEB4      15
```

```
PROGRAM WAVES2     74/74   OPT=1                         FTN 4.2+P380        03/27/75  18.17.02.      PAGE

            D(2)=.0280                                                    FEB4       16
            JJ=JJ+1                                                       WAVES2     41
            L=1                                                           WAVES2     42
        300 CONTINUE                                                      WAVES2     43
            LL=MA(L)                                                      WAVES2     44
            DLS=D(L)                                                      WAVES2     45
         11 CONTINUE                                                      WAVES2     56
          4 CONTINUE                                                      WAVES2     70
            IF(.NOT.SW1) GO TO 310                                        FEB4       17
            IF(LL.EQ.0)READ(5,504)NF                                      WAVES2     71
        504 FORMAT(2I5)                                                   FEB7        8
            IF(LL.EQ.0)READ(5,8)(M,F(L,J),KM(L,J),KE(L,J),AID1,AID2,AID3,J=1, WAVES2  72
           2NF)                                                           WAVES2     73
        310 CONTINUE                                                      FEB4       18
          8 FORMAT(I5,5F10.4,2A10,A5)                                     WAVES2     74
        631 CONTINUE                                                      WAVES2    103
        622 FORMAT(1X,*LAYER NO.*,1X,I5,2X,*MATERIAL*,1X,I5,2X,2A10,A5)   WAVES2    105
        623 FORMAT(1X,5F10.3)                                             WAVES2    106
        625 CONTINUE                                                      WAVES2    107
            IF(L.EQ.NL)GO TO 645                                          WAVES2    108
            L=L+1                                                         WAVES2    109
            GO TO 300                                                     WAVES2    110
        500 FORMAT(2I5,3F10.4)                                            WAVES2    111
        501 FORMAT(13F6.2)                                                WAVES2    112
        502 FORMAT(5(F10.4,I5))                                           WAVES2    113
        645 CONTINUE                                                      WAVES2    114
            GOTO30                                                        WAVES2    119
            GO TO 30                                                      WAVES2    121
         30 CONTINUE                                                      WAVES2    123
            DT=0.0                                                        WAVES2    124
            DO 629 I=1,NL                                                 WAVES2    125
            DTOT=DT+D(I)                                                  WAVES2    126
            DT=DTOT                                                       WAVES2    127
        629 CONTINUE                                                      WAVES2    128
        626 FORMAT(1X,*TOTAL DESIGN THICKNESS=*,F10.4,*CMS*)              WAVES2    129
            F1=FINT                                                       WAVES2    132
         28 CONTINUE                                                      WAVES2    133
            DO 611 IL=1,NL                                                WAVES2    134
            II=1                                                          WAVES2    135
        612 CONTINUE                                                      WAVES2    136
            IF(ABS(F1-F(IL,II)).LE..001)GO TO 613                         WAVES2    137
            IF(F1.LE.F(IL,II))GOTO613                                     WAVES2    138
            II=II+1                                                       WAVES2    139
            GOTO612                                                       WAVES2    140
        613 INT(IL)=II                                                    WAVES2    141
        611 CONTINUE                                                      WAVES2    142
            DO 29 NN=1,NL                                                 WAVES2    143
            NJ=INT(NN)                                                    WAVES2    144
            IF(ABS(F1-F(IL,II)).LE..001)GO TO 619                         WAVES2    145
            FJJ=F(NN,NJ-1)                                                WAVES2    146
            GO TO 620                                                     WAVES2    147
        619 CONTINUE                                                      WAVES2    148
            FJJ=F(NN,NJ)                                                  WAVES2    149
        620 CONTINUE                                                      WAVES2    150
            IF(NJ.EQ.1)NJ1=NJ                                             WAVES2    151
            IF(NJ.NE.1)NJ1=NJ-1                                           WAVES2    152
            CALL INTERP(F1,FJJ,F(NN,NJ),KE(NN,NJ1),KE(NN,NJ),KM(NN,NJ1),KM(NN, WAVES2 153
```

```
      PROGRAM WAVES2     74/74    OPT=1                FTN 4.2+P380      03/27/75  18.17.02.      PAGE

     2NJ),K=1,KM1)
      KA(NN)=KE1
      KU(NN)=KM1
   29 CONTINUE
      FJJ=F1
   27 F1=FJJ+FINC
      IF(F1.GT.FFIN)CAEXIT=CAEXIT+1
      OLAM=29.9776/FJJ
      TEZ(NL+1)=1.
      TMZ(NL+1)=1.
      TEZSC(NL+1)=0.
      TMZSC(NL+1)=0.
      PHI(NL+1)=0.
      DO 1 L=1,NB
      THETA(L)=PI*BETA(L)/180.
      DO 2 J=1,NL
      ER=REAL(KA(J))
      IF(MA(J).EQ.-1)GOTO33
      IF(ER.LE.0.)CALL RLC(KA(J),KU(J),D(J),OLAM)
   33 CONTINUE
      K(J)=KU(J)*KA(J)
      TMZ(J)=CSQRT(K(J)-SIN(THETA(L))*SIN(THETA(L)))/(KA(J)*COS(THETA(L)
     *))
      TEZ(J)=KU(J)*COS(THETA(L))/CSQRT(K(J)-SIN(THETA(L))*SIN(THETA(L)))
      TMZSC(J)=TMZ(J)
      TEZSC(J)=TEZ(J)
      PHI(J)=2.0*PI*D(J)*CSQRT(K(J)-SIN(THETA(L))*SIN(THETA(L)))/OLAM
      IF(J.NE.1)GOTO3
      RTE(J)=(TEZ(J)-1.0)/(TEZ(J)+1.0)
      RTM(J)=(TMZ(J)-1.0)/(TMZ(J)+1.0)
      IF(J.EQ.NL)GOTO51
      RTESC(J)=(TEZSC(J)-1.0)/(TEZSC(J)+1.0)
      RTMSC(J)=(TMZSC(J)-1.0)/(TMZSC(J)+1.0)
      GOTO6
    3 CONTINUE
      RTE(J)=(TEZ(J)-TEZ(J-1))/(TEZ(J)+TEZ(J-1))
      RTM(J)=(TMZ(J)-TMZ(J-1))/(TMZ(J)+TMZ(J-1))
      IF(J.EQ.NL)GOTO5
      RTESC(J)=(TEZSC(J)-TEZSC(J-1))/(TEZSC(J)+TEZSC(J-1))
      RTMSC(J)=(TMZSC(J)-TMZSC(J-1))/(TMZSC(J)+TMZSC(J-1))
      GOTO6
   51 EMI=CEXP(-IM*PHI(J))
      EPI=CEXP(IM*PHI(J))
      TAN=(EPI-EMI)/(EPI+EMI)
      RTESC(J)=(TEZSC(J)*TAN-1.0)/(TEZSC(J)*TAN+1.0)
      RTMSC(J)=(TMZSC(J)*TAN-1.0)/(TMZSC(J)*TAN+1.0)
      GOTO6
    5 EMI=CEXP(-IM*PHI(J))
      EPI=CEXP(IM*PHI(J))
      TAN=(EPI-EMI)/(EPI+EMI)
      RTESC(J)=(TEZSC(J)*TAN-TEZSC(J-1))/(TEZSC(J)*TAN+TEZSC(J-1))
      RTMSC(J)=(TMZSC(J)*TAN-TMZSC(J-1))/(TMZSC(J)*TAN+TMZSC(J-1))
    6 CONTINUE
      TTM(J)=RTM(J)+1.0
      TTE(J)=RTE(J)+1.0
      TTMSC(J)=RTMSC(J)+1.0
      TTESC(J)=RTESC(J)+1.0
```

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PROGRAM WAVES2      74/74   OPT=1                          FTN 4.2+P380      03/27/75  18.17.02.      PAGE

    2  CONTINUE                                                              WAVES2
       RTM(NL+1)=(TMZ(NL+1)-TMZ(NL))/(TMZ(NL+1)+TMZ(NL))                     WAVES2
       RTE(NL+1)=(TEZ(NL+1)-TEZ(NL))/(TEZ(NL+1)+TEZ(NL))                     WAVES2
       RTMSC(NL+1)=0.                                                        WAVES2
       RTESC(NL+1)=0.                                                        WAVES2
       TTMSC(NL+1)=RTMSC(NL+1)+1.0                                           WAVES2
       TTESC(NL+1)=RTESC(NL+1)+1.0                                           WAVES2
       TTM(NL+1)=RTM(NL+1)+1.0                                               WAVES2
       TTE(NL+1)=RTE(NL+1)+1.0                                               WAVES2
       NP1=NL+1                                                              WAVES2
       DO 40 K1=1,NP1                                                        WAVES2
       DO 20 J=1,2                                                           WAVES2
       DO 20 I=1,2                                                           WAVES2
       R1=CMPLX(1.0,0.)                                                      WAVES2
       R2=R1                                                                 WAVES2
       R3=R1                                                                 WAVES2
       R4=R1                                                                 WAVES2
       IF(I.NE.J)R1=RTE(K1)                                                  WAVES2
       IF(I.NE.J)R2=RTM(K1)                                                  WAVES2
       IF(I.NE.J)R3=RTESC(K1)                                                WAVES2
       IF(I.NE.J)R4=RTMSC(K1)                                                WAVES2
       S=1.0                                                                 WAVES2
       IF(J.EQ.2)S=-1.0                                                      WAVES2
       AE(I,J)=1.0                                                           WAVES2
       AM(I,J)=1.0                                                           WAVES2
       AES(I,J)=1.0                                                          WAVES2
       AMS(I,J)=1.0                                                          WAVES2
       IF(I.NE.J)AE(I,J)=0.                                                  WAVES2
       IF(I.NE.J)AM(I,J)=0.                                                  WAVES2
       IF(I.NE.J)AES(I,J)=0.                                                 WAVES2
       IF(I.NE.J)AMS(I,J)=0.                                                 WAVES2
       IF(K1.NE.1)AES(I,J)=CES(I,J)                                          WAVES2
       IF(K1.NE.1)AMS(I,J)=CMS(I,J)                                          WAVES2
       IF(K1.NE.1)AE(I,J)=CE(I,J)                                            WAVES2
       IF(K1.NE.1)AM(I,J)=CM(I,J)                                            WAVES2
       CES(I,J)=0.                                                           WAVES2
       CMS(I,J)=0.                                                           WAVES2
       CE(I,J)=0.                                                            WAVES2
       CM(I,J)=0.                                                            WAVES2
       BE(I,J)=R1*CEXP(S*IM*PHI(K1))                                         WAVES2
       BM(I,J)=R2*CEXP(S*IM*PHI(K1))                                         WAVES2
       PHIK=PHI(K1)                                                          WAVES2
       IF(K1.EQ.NL)PHIK=0.                                                   WAVES2
       BES(I,J)=R3*CEXP(S*IM*PHIK)                                           WAVES2
   20  BMS(I,J)=R4*CEXP(S*IM*PHIK)                                           WAVES2
       DO 50 M=1,2                                                           WAVES2
       DO 50 L1=1,2                                                          WAVES2
       DO 50 N1=1,2                                                          WAVES2
       CE(L1,M)=CE(L1,M)+(AE(L1,N1)*BE(N1,M))/TTE(K1)                        WAVES2
       CM(L1,M)=CM(L1,M)+(AM(L1,N1)*BM(N1,M))/TTM(K1)                        WAVES2
       CES(L1,M)=CES(L1,M)+(AES(L1,N1)*BES(N1,M))/TTESC(K1)                  WAVES2
   50  CMS(L1,M)=CMS(L1,M)+(AMS(L1,N1)*BMS(N1,M))/TTMSC(K1)                  WAVES2
   40  CONTINUE                                                              WAVES2
       A=CABS(CE(2,1)/CE(1,1))                                               WAVES2
       B=CABS(CM(2,1)/CM(1,1))                                               WAVES2
       C=CABS(CES(2,1)/CES(1,1))                                             WAVES2
       E=CABS(CMS(2,1)/CMS(1,1))                                             WAVES2
```

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PROGRAM WAVES2      74/74    OPT=1                         FTN 4.2+P380       03/27/75  18.17.02.       PAGE

      TE=-20.0*ALOG10(CABS(1.0/CE(1,1)))                                          WAVES2   268
      PHIE=-(ATAN2(AIMAG(CE(1,1)),REAL(CE(1,1)))*180.0/PI)+360.0*DTOT*            WAVES2   269
     1COS(THETA(L))/OLAM                                                          WAVES2   270
      IF(PHIE.GT.0.0)PHIE=PHIE-360.0                                              WAVES2   271
      TM=-20.0*ALOG10(CABS(1.0/CM(1,1)))                                          WAVES2   272
      PHIM=-(ATAN2(AIMAG(CM(1,1)),REAL(CM(1,1)))*180.0/PI)+360.0*DTOT*            WAVES2   273
     1COS(THETA(L))/OLAM                                                          WAVES2   274
      IF(PHIM.GT.0.0)PHIM=PHIM-360.0                                              WAVES2   275
      IF(A.EQ.0.)GO TO 45                                                         WAVES2   276
      RE=-20.0*ALOG10(CABS(CE(2,1)/CE(1,1)))                                      WAVES2   277
      CET=CE(2,1)/CE(1,1)                                                         WAVES2   278
      PHIET=ATAN2(AIMAG(CET),REAL(CET))*180.0/PI                                  WAVES2   279
      IF(PHIET.LT.0.0)PHIET=360.0+PHIET                                           WAVES2   280
   48 IF(B.EQ.0.)GO TO 46                                                         WAVES2   281
      RM=-20.0*ALOG10(CABS(CM(2,1)/CM(1,1)))                                      WAVES2   282
      CMT=CM(2,1)/CM(1,1)                                                         WAVES2   283
      PHIMT=ATAN2(AIMAG(CMT),REAL(CMT))*180.0/PI                                  WAVES2   284
      IF(PHIMT.LT.0.0)PHIMT=360.0+PHIMT                                           WAVES2   285
      GO TO 47                                                                    WAVES2   286
   45 RE=-10.0**38                                                                WAVES2   287
      GO TO 48                                                                    WAVES2   288
   46 RM=-10.0**38                                                                WAVES2   289
   47 IF(C.EQ.0.)GOTO41                                                           WAVES2   290
      RESC=-20.0*ALOG10(CABS(CES(2,1)/CES(1,1)))                                  WAVES2   291
      YN=(CES(1,1)-CES(2,1))/(CES(1,1)+CES(2,1))                                  WAVES2   292
      ZN=1.0/YN                                                                   WAVES2   293
      ZNM=CABS(ZN)                                                                WAVES2   294
      ZNP=ATAN2(AIMAG(ZN),REAL(ZN))*180./PI                                       WAVES2   295
   44 IF(E.EQ.0.)GOTO42                                                           WAVES2   296
      RMSC=-20.0*ALOG10(CABS(CMS(2,1)/CMS(1,1)))                                  WAVES2   297
      GOTO43                                                                      WAVES2   298
   41 RESC=-10.0**38                                                              WAVES2   299
      GOTO44                                                                      WAVES2   300
   42 RMSC=-10.0**38                                                              WAVES2   301
   43 CONTINUE                                                                    WAVES2   302
      WRITE(10)FJJ,BETA(L),RE,PHIET,TE,PHIE,RM,PHIMT,TM,PHIM                      WAVES2   303
    1 CONTINUE                                                                    WAVES2   309
  601 FORMAT(1X)                                                                  WAVES2   311
      IF(CAEXIT.EQ.JD)GO TO 621                                                   WAVES2   312
      SH1=.FALSE.                                                                 FEB4      19
      GOTO28                                                                      WAVES2   313
  602 FORMAT(1X/2X,11HFRONT LAYER,3X,1HD,I2,1H=,F8.4,3HCMS)                       WAVES2   314
  603 FORMAT(2X,9HLAYER NO.,I2,3X,1HD,I2,1H=,F8.4,3HCMS)                          WAVES2   315
  604 FORMAT(2X,10HBACK LAYER,4X,1HD,I2,1H=,F8.4,3HCMS)                           WAVES2   316
  605 FORMAT(1X/1X/3X,21HFREQUENCY      INCIDENT,4X,3HRTE,4X,*ANGLE*,6X,          WAVES2   317
     13HTTE,4X,*ANGLE*,6X,3HRTM,5X,*ANGLE*,8X,3HTTM,4X,*ANGLE*,3X,                WAVES2   318
     25HRSCTE,2X,5HRSCTM,5X,13HIMPEDANCE(TE)/5X,5H(GHZ),6X,10HANGLE(DEG)          WAVES2   319
     A,2X,4H(DB),                                                                 WAVES2   320
     34X,*DEG*,7X,4H(DB),5X,*DEG*,6X,4H(DB),5X,*DEG*,6X,4H(DB),7X,                WAVES2   321
     4*DEG*,4X,4H(DB),4X,4H(DB),5X,3HAMP,5X,5HPHASE/1X)                           WAVES2   322
  610 FORMAT(2X,F7.2,4X,F8.3,5X,10(F7.2,2X),F6.2,F8.2)                            WAVES2   323
      END                                                                         WAVES2   324
```

```
SUBROUTINE RLC        74/74   OPT=1             FTN 4.2+P380     03/27/75  10.17.40.       PAGE

      SUBROUTINE RLC(KE,KM,D,OLAM)                                          RLC        2
      COMPLEX KE,KM,IM,Y                                                    RLC        3
      FR=AIMAG(KE)                                                          RLC        4
      B=REAL(KE)                                                            RLC        5
      Q=REAL(KM)                                                            RLC        6
      G=AIMAG(KM)                                                           RLC        7
      IM=CMPLX(0.,1.)                                                       RLC        8
      P=3.14159265                                                          RLC        9
      F=(29977.6/OLAM)/1000.                                                RLC       10
      A=F/FR                                                                RLC       11
      YII=B*A                                                               RLC       12
      A=(A*A-1.)/A                                                          RLC       13
      YDEN=1.+Q*Q*A*A                                                       RLC       14
      YR=G/YDEN                                                             RLC       15
      YI=G*Q*A/YDEN                                                         RLC       16
      YI=YII+YI                                                             RLC       17
      Y=CMPLX(YR,-YI)                                                       RLC       18
      KE=Y*OLAM/(IM*2.*P*D)                                                 RLC       19
      KM=CMPLX(1.0,0.0)                                                     RLC       20
      RETURN                                                                RLC       21
      END                                                                   RLC       22
```

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SUBROUTINE INTERP     74/74    OPT=1                    FTN 4.2+P380     03/27/75   18.17.52.      PAGE

      SUBROUTINE INTERP(F1,B,B1,C1,C,D1,D,KE1,KM1)
      COMPLEX KE1,KM1,C,C1,D,D1
      ERMAX=REAL(C1)
      ERMIN=REAL(C)
      EIMAX=AIMAG(C1)
      EIMIN=AIMAG(C)
      URMAX=REAL(D1)
      URMIN=REAL(D)
      UIMAX=AIMAG(D1)
      UIMIN=AIMAG(D)
      IF(ABS(B-B1).LE..001)GO TO30
      FRAC=(B1-F1)/(B1-B)
      GO TO 31
   30 FRAC=0.0
   31 CONTINUE
      ERMED=FRAC*(ERMAX-ERMIN)
      EIMED=FRAC*(EIMAX-EIMIN)
      URMED=FRAC*(URMAX-URMIN)
      UIMED=FRAC*(UIMAX-UIMIN)
      ER=ERMIN+ERMED
      EI=EIMIN+EIMED
      UR=URMIN+URMED
      UI=UIMIN+UIMED
      KE1=CMPLX(ER,EI)
      KM1=CMPLX(UR,UI)
      RETURN
      END
```

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SUBROUTINE STRIPS       74/74    OPT=1                       FTN 4.2+P380      03/27/75  10.1?.??.

      SUBROUTINE STRIPS(YLN,F1,NFS)                                        STRIPS      2
C  NSETS  NUMBER OF DATA SETS INCLUDED WITH THIS RUN                       STRIPS      3
C  FMIN   LOWER FREQUENCY LIMIT IN GHZ.                                    STRIPS      4
C  FMAX   UPPER FREQUENCY LIMIT IN GHZ.                                    STRIPS      5
C  DELF   FREQUENCY INCREMENT IN GHZ.                                      STRIPS      6
C  DX     STRIP SPACING IN CM.                                             STRIPS      7
C  W      STRIP WIDTH IN CM.                                               STRIPS      8
C  G      RELATIVE SHEET CONDUCTANCE IN MHO PER SQUARE                     STRIPS      9
C  TH     STRIP THICKNESS IN CM.                                           STRIPS     10
C  DZ     SPACING BETWEEN CUTS IN CM.                                      STRIPS     11
C  ESUB   RELATIVE DIELECTRIC CONSTANT OF SUBSTRATE                        STRIPS     12
C  TSUB   SUBSTRATE THICKNESS IN CM.                                       STRIPS     13
C  GW     CUT WIDTH IN CM.                                                 STRIPS     14
C  CSS    SHUNT CAP. ACROSS R AND L DUE TO SUBSTRATE IN PICOFARADS         STRIPS     15
C  CSC    SHUNT CAP.ACROSS ZL DUE TO X-POL. DIELECTRIC STRIPS IN PICOFAR   STRIPS     16
C  CF     CONSTRUCTION FACTOR      =0 IF NO ORTHOGONAL ARRAY PRESENT       STRIPS     17
C                                  =1 IF ONE LAYER WITH ORTHOGONAL ARRAY   STRIPS     18
C                                  =2 IF TWO LAYERS WITH ORTHOGONAL ARRAY  STRIPS     19
      INTEGER PHI,CF                                                       STRIPS     20
      COMPLEX FM,FMK,B,SUM1,SUM2,SUM3,SUM4,SUM5,RS,ZL,E,TERM1,TERM2,TERM   STRIPS     21
     3M3,TERM4,R,T,ZS,REFLC,ZOC,ZCSC,YL,YLN(30)                            STRIPS     22
      DIMENSION REFLR(90),REFLI(90),F1(30)                                 STRIPS     23
      NSETS=1                                                              STRIPS     24
      NFS=1                                                                STRIPS     25
      DO 40 NSET=1,NSETS                                                   STRIPS     26
      READ(5,1) FMIN, FMAX,DELF,DX,W,G,TH,DZ,ESUB,TSUB,GW,CF                STRIPS     27
    1 FORMAT(6F10.6,/3F10.6,1X,I1)                                         STRIPS     28
      IF(DELF.GT.0.0)GO TO 210                                             STRIPS     29
      WRITE(6,205)                                                         STRIPS     30
  205 FORMAT(51H FREQUENCY INCREMENT MUST BE A POSITIVE REAL NUMBER)       STRIPS     31
      GO TO 40                                                             STRIPS     32
  210 IF(W.GT.0.0.AND.(DX-W).GT.0.0)GO TO 220                              STRIPS     33
      WRITE(6,215)                                                         STRIPS     34
  215 FORMAT(81H STRIP SPACING MUST BE GREATER THAN STRIP WIDTH AND BOTH   STRIPS     35
     H MUST BE POSITIVE NUMBERS)                                           STRIPS     36
      GO TO 40                                                             STRIPS     37
  220 IF(TH.GT.0.0)GO TO 230                                               STRIPS     38
      WRITE(6,225)                                                         STRIPS     39
  225 FORMAT(42H STRIP THICKNESS MUST BE A POSITIVE NUMBER)                STRIPS     40
      GO TO 40                                                             STRIPS     41
  230 FPI2=2.0*3.14159265                                                  STRIPS     42
      SIGMA= 100.*G/(377.0*TH)                                             STRIPS     43
      IF((DZ-GW).GT.0.0.OR.GW.EQ.0.0)GO TO 232                             STRIPS     44
      WRITE(6,231)                                                         STRIPS     45
  231 FORMAT(43H CUT SPACING MUST BE GREATER THAN CUT WIDTH)               STRIPS     46
      GO TO 40                                                             STRIPS     47
  232 IF(GW)235,237,240                                                    STRIPS     48
  235 WRITE(6,236)                                                         STRIPS     49
  236 FORMAT(29H GAP WIDTH CANNOT BE NEGATIVE)                             STRIPS     50
      GO TO 40                                                             STRIPS     51
  237 DZ=1.0                                                               STRIPS     52
      C=0.25                                                               STRIPS     53
      A=W/4.0                                                              STRIPS     54
      CSQ=0.0                                                              STRIPS     55
      ESUBE=1.0                                                            STRIPS     56
      GO TO 245                                                            STRIPS     57
  240 CALL CSQARE(ESUB,TSUB,DZ,GW,W,DX,ESUBE,CSQ,A,C,TH)                   STRIPS     58
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SUBROUTINE STRIPS      74/74    OPT=1                    FTN 4.2+P380        03/27/75  18.17.54.      PAGE

  245 IF(CF.NE.0)A=A/(1.0-0.31*N, .)
      CSS= (ESUB-1.0)*TSUB/(1.80*FPI2)
      CSC= X*W/(14.4*DX)
      WRITE(6,2)FMIN, FMAX,DELF,DX,W,G,TH,DZ,SIGMA,GW,CSQ,CSS,TSUB,ESUB,
     ZESUBE
    2 FORMAT (29H FREQUENCY SCAN FROM,F10.3,7H GHZ TO,F10.3,21H GHZ IN I
     2NCREMENTS OF,F10.3,4H GHZ,/24H SPACING BETWEEN STRIPS=,F10.6,3H CM
     3,/13H STRIP WIDTH=,F10.6,3H CM,/23H REL SHEET CONDUCTANCE=,F10.6
     4,16H MHOS PER SQUARE,/ 17H STRIP THICKNESS=,F10.6,3H CM,/ 13H CUT
     5SPACING=,F10.6,3H CM,/ 7H SIGMA=,E12.6,14H MHO PER METER,/
     *11H GAP WIDTH=,F10.6,3H CM/
     628H SERIES CAPACITANCE=,F10.6,11H PICOFARADS,/36H SHUNT CAPACITANC
     7E DUE TO SUBSTRATE=,F10.6,11H PICOFARADS,/21H SUBSTRATE THICKNESS=
     8,F10.6,3H CM,/35H SUBSTRATE REL DIELECTRIC CONSTANT=,F10.6/
     931H EFFECTIVE DIELECTRIC CONSTANT=,F10.6)
      IF (CF.EQ.0) WRITE(6,5)
      IF (CF.EQ.1) WRITE(6,6)
      IF (CF.EQ.2) WRITE(6,7)
    5 FORMAT(43H LAYER CONSTRUCTED WITH NO ORTHOGONAL ARRAY)
    6 FORMAT(45H ORTHOGONAL ARRAY IN SAME PLANE AS BASE ARRAY)
    7 FORMAT(45H ORTHOGONAL ARRAY PLACED ON TOP OF BASE ARRAY)
      FPHI=0.0
      SPHI=SIN(FPI2*FPHI/360.)
      CPHI=COS(FPI2*FPHI/360.)
      F=FMIN
   41 CONTINUE
      FLAM=30./F
      BETA=FPI2/FLAM
      BDX=BETA*DX
      SUM1=(0.0,0.0)
      N=0
    8 N=N+1
      FN=FLOAT(N)
      DEN1=BDX*BDX-(BDX*SPHI+FPI2*FN)**2
      IF (DEN1) 10,10,9
    9 DEN1=SQRT(DEN1)
      TERM1=2.0/DEN1
      SUM1=SUM1+TERM1
      GO TO 8
   10 N1=N-1
      SUM2=(0.0,0.0)
      N=0
   11 N=N+1
      FN=FLOAT(N)
      DEN2=BDX*BDX-(BDX*SPHI-FPI2*FN)**2
      IF(DEN2) 13,13,12
   12 DEN2=SQRT(DEN2)
      TERM2=2.0/DEN2
      SUM2=SUM2+TERM2
      GO TO 11
   13 N2=N-1
      SUM3=(0.0,0.0)
      N=N1
   14 N=N+1
      FN=FLOAT(N)
      DEN3=SQRT((BDX*SPHI+FPI2*FN)**2-BDX*BDX)
      TERM3=CMPLX(0.0,2.0*EXP(-A*DEN3/DX)/DEN3)
```

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SUBROUTINE STRIPS      74/74    OPT=1                    FTN 4.2+P380       03/27/75  18.17.54.        PAGE

      IF(CABS(TERM3).LT.1.0E-6) GO TO 15
      SUM3=SUM3+TERM3
      GO TO 14
   15 N3=N-N1
      SUM4=(0.0,0.0)
      N=N2
   16 N=N+1
      FN=FLOAT(N)
      DEN4=SQRT((BDX*SPHI-FPI2*FN)**2-BDX*BDX)
      TERM4=CMPLX(0.0,2.0*EXP(-A*DEN4/DX)/DEN4)
      IF(CABS(TERM4).LT.1.0E-6) GO TO 17
      SUM4=SUM4+TERM4
      GO TO 16
   17 N4=N-N2
      SUM5=2.0*(CEXP(CMPLX(0.0,-BETA*A*CPHI)))/(BDX*CPHI)
      FM=-(SUM1+SUM2+SUM3+SUM4+SUM5)
      E=CMPLX ( 1.0, -SIGMA/(FPI2*F*8.852E-03))
      FM=(0.0,8.)/(FPI2*E*A*A*BETA*BETA)+FM
      FMK=(1.0,0.0)
      B=FMK/FM
      BMAG=CABS(B)
      BPH=(360./FPI2)*ATAN2(AIMAG(B),REAL(B))
      R=-B/((FPI2/2.0)*DX*CPHI/FLAM)
      RPH=(360.0/FPI2)*ATAN2(AIMAG(R),REAL(R))
      RMAG=CABS(R)
   89 RDB=-20.0*ALOG10(RMAG)
      T=1.-R
      TMAG=CABS(T)
      TPH=(360.0/FPI2)*ATAN2(AIMAG(T),REAL(T))
      TDB=-20.0*ALOG10(TMAG)
      FLOSS=1.0-RMAG*RMAG-TMAG*TMAG
      ZS=30.*FPI2*(1.-R)/(R*CPHI)
      XL=AIMAG(ZS)
      XL=XL*4.0*C/DZ
      FLL=XL/(FPI2*F)
      Y0=60.*FPI2/XL
      SCR=10.0
      I2F=IFIX(F*2.0)
      ZOC= CMPLX( 60.0*FPI2 /CPHI , 0.0)
      RL= 60.0*FPI2*DX/(W*G)
      RL=RL*DZ/(4.0*C)
      IF (CF.EQ.1) RL=RL*(1.0-0.31*W/DX)
      IF (CF.EQ.2) RL=RL*(1.0-0.592*W/DX)
      IF((N1.NE.0).OR.(N2.NE.0))  RL=2.0*FLOAT(N1+N2)*RL
      Q=XL/RL
      IF(GW.EQ.0.0)GO TO 260
      XCSQ=  1.0E+03/(FPI2*F*CSQ)
      GO TO 265
  260 XCSQ=0.0
  265 IF(CSS.EQ.0.0)GO TO 270
      XCSS= 1.0E+03/(FPI2*F*CSS)
      ZDEN= RL*RL+(XL-XCSS)*(XL-XCSS)
      ZL=CMPLX(RL*XCSS*XCSS/ZDEN,-XCSQ-XCSS*(RL*RL+XL*XL-XL*XCSS)/ZDEN)
      GO TO 275
  270 ZL=CMPLX(RL,-XCSQ+XL)
  275 IF(CF.NE.0) GO TO 100
      REFLC=-(ZL-ZOC)/(ZL+ZOC)
```

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SUBROUTINE STRIPS      74/74    OPT=1                    FTN 4.2+P380         03/27/75  18.17.54.        PAGE

              GO TO 101
          100 ZCSC=CMPLX(0.0,-1.0E+3/(FPI2*F*CSC*CPHI))
              ZL = ZL*ZCSC/(ZL+ZCSC)
              REFLC=-(ZL-ZOC)/(ZL+ZOC)
          101 CONTINUE
              REFLR(I2F)= REAL(REFLC)*SCR
              REFLI(I2F)= AIMAG(REFLC)*SCR
              YL=1.0/ZL
              YLN(NFS)=YL*ZOC
              F1(NFS)=F
              NFS=NFS+1
              F=F+DELF
              IF(F.LE.FMAX) GO TO 41
              NFS=NFS-1
           40 CONTINUE
              RETURN
              END
```

```
   SUBROUTINE CSQARE      74/74    OPT=1                 FTN 4.2+P380      03/27/75  18.18.10.     PAGE

            SUBROUTINE CSQARE(ESUB,TSUB,DZ,GW,W,DX,ESUBE,CSQ,RHO,C,TH)        CSQARE    2
            INTEGER CFP                                                       CSQARE    3
            RSQ=W*W/16.0                                                      CSQARE    4
            H=(DZ+GW)/4.0                                                     CSQARE    5
            X1=GW/2.0                                                         CSQARE    6
            X2=DZ/2.0                                                         CSQARE    7
         10 C=SQRT(((H*H+H*X1-X1*X1)*H-X2*X2*X1)/(H-X1))                      CSQARE    8
            A=(C+SQRT(C*C+RSQ))*(2.0*H-C+SQRT((2.0*H-C)*(2.0*H-C)+RSQ))/((-C+S CSQARE    9
           *SQRT(C*C+RSQ))*(2.0*H+C+SQRT((2.0*H+C)*(2.0*H+C)+RSQ)))           CSQARE   10
            X2C=SQRT(((H-C)*(H-C)-A*(H+C)*(H+C))/(1.0-A))                     CSQARE   11
            T=X2/X2C                                                          CSQARE   12
            IF(ABS(T-1.0).LT.1.0E-6)GO TO 20                                  CSQARE   13
            H=H*T                                                             CSQARE   14
            GO TO 10                                                          CSQARE   15
         20 F=C*(1.0+A)/(1.0-A)                                               CSQARE   16
            X1C=F+SQRT(F*F+H*H-C*C)                                           CSQARE   17
            PH1=ALOG(A)                                                       CSQARE   18
            B=(ESUB-1.0)/(ESUB+1.0)                                           CSQARE   19
            BS=B*B                                                            CSQARE   20
            BN=B*(1.0-BS)                                                     CSQARE   21
            PHN=(1.0-B)*PH1                                                   CSQARE   22
            RHO=W/4.0                                                         CSQARE   23
            XX2=2.0*H+C                                                       CSQARE   24
            XX3=2.0*H-C                                                       CSQARE   25
            X2S=XX2*XX2                                                       CSQARE   26
            X3S=XX3*XX3                                                       CSQARE   27
            Z=2.0*TSUB+RHO                                                    CSQARE   28
         30 ZS=Z*Z                                                            CSQARE   29
            R1=SQRT(ZS+C*C)                                                   CSQARE   30
            R2=SQRT(ZS+X2S)                                                   CSQARE   31
            R3=SQRT(ZS+X3S)                                                   CSQARE   32
            PHP=BN*ALOG((R1+C)*(XX3+R3)/((R1-C)*(XX2+R2)))+PHN                CSQARE   33
            U=PHN/PHP                                                         CSQARE   34
            PHN=PHP                                                           CSQARE   35
            IF(ABS(U-1.0).LT.1.0E-6)GO TO 40                                  CSQARE   36
            BN=BN*BS                                                          CSQARE   37
            Z=Z+2.0*TSUB                                                      CSQARE   38
            GO TO 30                                                          CSQARE   39
         40 ESUBE=PH1/PHN                                                     CSQARE   40
            READ(5,1)CFP                                                      CSQARE   41
          1 FORMAT(I2)                                                        CSQARE   42
            IF(CFP.EQ.1)GO TO 45                                              CSQARE   43
            ESUBE=2.0*ESUBE-1.0                                               CSQARE   44
            PHN=PH1/ESUBE                                                     CSQARE   45
         45 CSQ=(DZ*C)/(8.90*DX*PHN)                                          CSQARE   46
            CSQ=CSQ+0.085*W*TH/GW                                             CSQARE   47
         50 CONTINUE                                                          CSQARE   48
            RETURN                                                            CSQARE   49
            END                                                               CSQARE   50
```

3. THE LISTING PROGRAM

The "listing" program will read the magnetic tape containing the flat-panel program outputs, and print out the electrical parameters required for each array element. The program list consists of the following for a given antenna array row or column:

(I,J)	-	array row and column numbers, respectively
—	-	incidence angle in degrees
RTE	-	reflection loss in dB for vertical polarization (power)
ANGLE	-	electrical angle after reflection
TTT	-	transmission loss for vertical polarization in dB (power)
Angle	-	insertion phase delay (Deg)
RTM	-	reflection loss for horizontal polarization dB (power)
ANGLE	-	phase angle in electrical degrees after reflection
TTM	-	insertion loss for horizontal polarization in dB (power)
ANGLE	-	insertion phase delay in electrical degrees for horizontal polarization

a. WAVES2 INPUTS

The required data cards are:

1. Input magnetic tape from flat-panel program
2. One data card, on which will be entered:

In column 5: 1 = row output
2 = column output

and in columns 9 and 10: array row or column desired

Final printout of the array element modification parameters follows.

.b. WAVES2 OUTPUT

```
PROGRAM MAIN        74/74    OPT 1                          FTN 4.2+P390      04/01/75  09.15.27.        PAGE

              PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE8)
              DIMENSION XINCID(45,45)
C             1,2 IN COL 5 = ROW,COL AND 9 AND 10 ARE ROW OR COL NUM.
              READ(5,500)KOP,NUM
              PRINT(6,510)
        90    READ(5)THEL,THAZ
              IF(EOF(5).NE.0.)CALL EXIT
              PRINT(6,200)THEL,THAZ
              READ(5)IMAX,JMAX,K3,XINCID
              PRINT(6,530)IMAX,JMAX,K3
              PRINT(6,540)
              PRINT(6,541)
              DO 230 I=1,IMAX
              DO 210 J=1,JMAX
              IF(XINCID(I,J).GT.900.)GO TO 210
              DO 220 K=1,2
              READ(8)FJJ,DUMMY,RE,PHIET,TE,PHIE,RM,PHIMT,TM,PHIM
              IF(KOP.NE.1)GO TO 310
              IF(I.NE.NUM)GO TO 300
              GO TO 320
       310    IF(J.NE.NUM)GO TO 300
       320    CONTINUE
              PRINT(6,400)I,J,FJJ,DUMMY,RE,PHIET,TE,PHIE,RM,PHIMT,TM,PHIM
       300    CONTINUE
       220    CONTINUE
       210    CONTINUE
       230    CONTINUE
              GO TO 90
       200    FORMAT(1H0,*THEL=*,F10.4,1X,*THAZ=*,F10.4)
       400    FORMAT(1X,I2,*,*,I2,2X,F7.2,4X,F8.3,5X,8(F7.2,2X))
       500    FORMAT(2I5)
       510    FORMAT(1H1)
       530    FORMAT(1H0,*NUM OF ROWS=*,I2,3X,*NUM OF COLS=*,I2,3X,
             1*NUM OF VISIBLE RAYS =*,I4/)
       540    FORMAT(1X,*ELEMENT*,1X,*FREQUENCY*,1X,*INCIDENCE*,5X,*RTE*,5X,
             1*ANGLE*,7X,*TTE*,3X,*ANGLE*,6X,*RTM*,5X,*ANGLE*,7X,*TTM*,3X,*ANGLE
             1*)
       541    FORMAT(1X,*ROW,COL*,1X,*(GHZ)*,5X,*ANGLE(DEG)*,4X,*(DB)*,4X,
             1*(DEG)*,7X,*(DB)*,3X,*(DEG)*,5X,*(DB)*,4X,*(DEG)*,7X,*(DB)*,2X,
             1*(DEG)*/)
              END
```

THEL= 0.0000 THAZ= 5.0000

NUM OF ROWS=44 NUM OF COLS=44 NUM OF VISIBLE RAYS =19

ELEMENT ROW,COL	FREQUENCY (GHZ)	INCIDENCE ANGLE(DEG)	RTE (DB)	ANGLE (DEG)	TTE (DB)	ANGLE (DEG)	RTM (DB)	ANGLE (DEG)	TTM (DB)	ANGLE (DEG)
44, 1	9.70	73.331	14.32	119.48	.79	-135.22	27.14	292.16	.25	-140.87
44, 1	9.80	73.331	18.77	127.39	.63	-139.36	30.79	299.61	.25	-142.55
44, 2	9.70	73.252	15.11	119.49	.73	-135.17	27.27	292.22	.25	-140.76
44, 2	9.80	73.252	18.89	127.62	.62	-139.30	30.95	299.80	.25	-142.43
44, 3	9.70	73.423	14.81	119.47	.71	-135.26	26.99	292.11	.25	-141.00
44, 3	9.80	73.423	18.53	127.14	.63	-139.43	30.62	299.40	.25	-142.69
44, 4	9.70	72.888	14.83	118.93	.69	-134.20	27.29	291.67	.25	-139.92
44, 4	9.80	72.888	18.55	125.87	.62	-138.24	30.81	298.32	.25	-141.57
44, 5	9.70	73.559	15.22	120.09	.70	-136.06	27.31	292.79	.25	-141.49
44, 5	9.80	73.559	19.25	129.55	.63	-140.28	31.14	301.41	.25	-143.19
44, 6	9.70	72.842	14.88	118.93	.69	-134.18	27.37	291.70	.25	-139.86
44, 6	9.80	72.842	18.62	125.98	.62	-138.21	30.90	298.42	.25	-141.50
44, 7	9.70	73.695	15.06	120.05	.71	-136.14	27.08	292.69	.26	-141.68
44, 7	9.80	73.695	19.05	129.11	.64	-140.39	30.88	301.05	.25	-143.39
44, 8	9.70	72.805	14.93	118.93	.69	-134.16	27.43	291.72	.25	-139.80
44, 8	9.80	72.805	18.67	126.07	.61	-138.18	30.98	298.50	.25	-141.45
44, 9	9.70	73.845	14.88	120.02	.72	-136.22	26.84	292.59	.26	-141.90
44, 9	9.80	73.845	18.92	128.64	.64	-140.49	30.59	300.67	.25	-143.62
44,10	9.70	72.700	14.42	118.40	.70	-133.28	27.00	291.05	.25	-139.32
44,10	9.80	72.700	17.11	123.84	.62	-137.26	30.32	296.58	.25	-140.95
44,11	9.70	74.009	14.69	120.00	.73	-136.31	26.57	292.48	.26	-142.13
44,11	9.80	74.009	18.59	128.17	.65	-140.62	30.27	300.28	.26	-143.86
44,12	9.70	72.708	14.41	118.40	.70	-133.28	26.99	291.05	.25	-139.33
44,12	9.80	72.708	17.90	123.87	.62	-137.26	30.30	296.57	.25	-140.96
44,13	9.70	74.032	15.40	120.87	.71	-137.20	27.26	293.51	.26	-142.49
44,13	9.80	74.032	19.61	132.01	.64	-141.56	31.27	303.45	.25	-144.22
44,14	9.70	72.528	14.39	118.22	.70	-132.89	27.07	290.89	.25	-138.95
44,14	9.80	72.528	17.83	123.36	.62	-136.82	30.33	296.18	.24	-140.57
44,15	9.70	74.263	15.14	120.84	.73	-137.41	26.87	293.38	.26	-142.89
44,15	9.80	74.263	19.28	131.33	.65	-141.81	30.83	302.92	.26	-144.65
44,16	9.70	72.430	14.08	117.94	.70	-132.27	26.83	290.52	.25	-138.57
44,16	9.80	72.430	17.37	122.19	.62	-136.17	29.96	295.13	.24	-140.19
44,17	9.70	74.775	14.53	120.73	.76	-137.68	26.04	293.01	.27	-143.62
44,17	9.80	74.775	18.51	129.65	.68	-142.19	29.85	301.54	.26	-145.42
44,18	9.70	72.437	13.77	117.80	.72	-131.85	26.53	290.25	.25	-139.41
44,18	9.80	72.437	16.93	121.33	.63	-135.74	29.54	294.34	.24	-140.02
44,19	9.70	74.733	14.58	120.74	.76	-137.66	26.11	293.04	.27	-143.56
44,19	9.80	74.733	18.57	129.78	.68	-142.16	29.93	301.64	.26	-145.36
44,20	9.70	72.421	13.46	117.67	.73	-131.35	26.23	289.97	.25	-138.18
44,20	9.80	72.421	16.48	120.52	.64	-135.22	29.12	293.55	.24	-139.79
44,21	9.70	74.939	14.28	120.72	.78	-137.78	25.70	292.88	.27	-143.93
44,21	9.80	74.939	18.19	129.05	.69	-142.35	29.45	301.02	.26	-145.74
44,22	9.70	72.196	13.31	117.47	.73	-130.68	26.22	289.74	.25	-137.63
44,22	9.80	72.196	16.24	119.88	.64	-134.50	29.02	292.96	.24	-139.22
44,23	9.70	75.259	13.97	120.74	.80	-137.90	25.28	292.73	.27	-144.31
44,23	9.80	75.259	17.80	128.37	.71	-142.54	28.95	300.41	.27	-146.15
44,24	9.70	72.282	12.97	117.48	.75	-130.32	25.83	289.55	.25	-137.58
44,24	9.80	72.282	15.77	119.34	.65	-134.14	28.53	292.36	.24	-139.18
44,25	9.70	75.265	13.96	120.74	.80	-137.91	25.27	292.73	.27	-144.32
44,25	9.80	75.265	17.79	128.36	.71	-142.54	28.94	300.40	.27	-146.16
44,26	9.70	72.231	12.59	117.45	.77	-129.60	25.49	289.30	.25	-137.21
44,26	9.80	72.231	15.23	118.66	.66	-133.38	28.04	291.61	.24	-138.80
44,27	9.70	75.272	13.95	120.74	.80	-137.91	25.25	292.72	.27	-144.33
44,27	9.80	75.272	17.73	128.34	.71	-142.55	28.93	300.38	.27	-146.17
44,28	9.70	72.361	12.46	117.54	.78	-129.65	25.29	289.29	.25	-137.39

[illegible]	9.5[illegible]	75.272	17.7[illegible]	128.74	.71	-142.55	28.93	300.38	.27	-146.17
44.29	9.70	72.361	12.46	117.44	.7[illegible]	-129.65	25.23	289.29	.25	-137.39
.28	9.90	77.361	15.79	119.54	.6[illegible]	-133.45	27.82	291.54	.24	-138.99
.29	9.70	75.289	13.34	120.74	.80	-137.91	25.24	292.72	.27	-144.34
44.29	9.90	75.293	17.77	128.32	.71	-142.55	28.92	300.37	.27	-146.18
44.30	9.70	72.161	11.97	117.53	.87	-128.43	24.93	289.99	.25	-136.63
44.[illegible]	9.80	72.151	14.37	117.31	.63	-132.15	27.29	290.64	.24	-138.21
44.31	9.70	75.298	13.33	120.74	.93	-137.92	25.23	292.71	.27	-144.35
44.31	9.88	75.233	17.75	128.30	.71	-142.56	28.90	300.35	.27	-146.19
44.32	9.70	72.307	11.35	117.66	.81	-128.49	24.71	289.00	.25	-136.82
44.32	9.80	72.307	14.23	117.73	.70	-132.24	27.04	290.58	.25	-138.41
44.33	9.70	75.297	13.92	120.75	.81	-137.92	25.22	292.71	.27	-144.37
44.33	9.80	75.297	17.74	128.28	.71	-142.57	28.89	300.33	.27	-146.20
44.34	9.70	72.362	11.18	118.04	.86	-127.33	24.00	288.82	.25	-136.39
44.34	9.80	72.362	13.33	117.60	.73	-131.04	26.13	289.84	.25	-137.97
44.35	9.70	75.307	13.91	120.75	.81	-137.92	25.20	292.70	.27	-144.38
44.35	9.80	75.307	17.73	128.26	.71	-142.57	28.87	300.31	.27	-146.22
44.36	9.70	72.558	11.92	118.25	.88	-127.39	23.71	288.85	.25	-136.65
44.36	9.80	72.558	13.13	117.70	.75	-131.13	25.83	289.80	.25	-138.24
44.37	9.70	76.995	12.05	121.53	.97	-138.49	22.66	292.15	.30	-146.71
44.37	9.80	76.995	15.41	125.68	.83	-143.60	25.94	297.54	.29	-148.72
44.38	9.70	72.518	10.50	118.65	.92	-126.24	23.21	288.78	.26	-136.09
44.38	9.80	72.518	12.44	117.65	.73	-129.92	25.17	289.35	.25	-137.67
44.39	9.70	77.119	11.92	121.63	.99	-138.52	22.48	292.13	.31	-146.88
44.39	9.80	77.119	15.25	125.57	.84	-143.66	25.74	297.39	.29	-148.90
44.40	9.70	72.529	9.99	119.19	.97	-125.17	22.67	288.81	.26	-135.63
44.40	9.80	72.529	11.78	117.83	.82	-128.79	24.50	289.05	.25	-137.22
44.41	9.70	77.242	11.79	121.74	1.00	-138.54	22.30	292.12	.31	-147.04
44.41	9.80	77.242	15.38	125.48	.85	-143.73	25.53	297.25	.30	-149.08
44.42	9.70	72.762	9.81	119.49	1.00	-125.22	22.35	288.87	.26	-135.93
44.42	9.80	72.762	11.57	118.05	.84	-128.87	24.16	289.07	.25	-137.53

THFL= 0.0000 THAZ= 5.0000

NUM OF ROWS=44 NUM OF COLS=44 NUM OF VISIBLE RAYS = 2

ELEMENT ROW,COL	FREQUENCY (GHZ)	INCIDENCE ANGLE(DEG)	RTE (DB)	ANGLE (DEG)	TTE (DB)	ANGLE (DEG)	RTM (DB)	ANGLE (DEG)	TTM (DB)	ANGLE (DEG)
1,44	9.70	71.008	13.78	116.74	.68	-129.04	27.43	289.46	.24	-135.54
1,44	9.80	71.008	16.70	119.23	.60	-132.64	30.20	292.54	.24	-137.07
2,44	9.70	71.008	13.78	116.74	.68	-129.04	27.43	289.46	.24	-135.54
2,44	9.80	71.008	16.70	119.23	.60	-132.64	30.20	292.54	.24	-137.07
3,44	9.70	71.024	13.77	116.75	.68	-129.05	27.41	289.46	.24	-135.56
3,44	9.80	71.024	16.68	119.22	.60	-132.65	30.17	292.52	.24	-137.09
4,44	9.70	71.024	13.77	116.75	.68	-129.05	27.41	289.46	.24	-135.56
4,44	9.80	71.024	16.68	119.22	.60	-132.65	30.17	292.52	.24	-137.09
5,44	9.70	71.071	13.72	116.77	.68	-129.07	27.33	289.45	.24	-135.63
5,44	9.80	71.071	16.62	119.18	.60	-132.68	30.09	292.48	.24	-137.16
6,44	9.70	71.071	13.72	116.77	.68	-129.07	27.33	289.45	.24	-135.63
6,44	9.80	71.071	16.62	119.18	.60	-132.68	30.09	292.48	.24	-137.16
7,44	9.70	71.120	13.67	116.79	.69	-129.10	27.25	289.44	.24	-135.69
7,44	9.80	71.120	16.56	119.15	.60	-132.71	30.00	292.44	.24	-137.23
8,44	9.70	71.120	13.67	116.79	.69	-129.10	27.25	289.44	.24	-135.69
8,44	9.80	71.120	16.56	119.15	.60	-132.71	30.00	292.44	.24	-137.23
9,44	9.70	71.012	13.59	116.70	.69	-128.75	27.24	289.33	.24	-135.43
9,44	9.80	71.012	16.42	118.84	.60	-132.35	29.94	292.15	.24	-136.95
10,44	9.70	71.056	13.54	116.72	.69	-128.78	27.17	289.32	.24	-135.49
10,44	9.80	71.056	16.37	118.81	.60	-132.39	29.86	292.12	.24	-137.01
11,44	9.70	71.137	13.46	116.76	.70	-128.82	27.03	289.31	.24	-135.60
11,44	9.80	71.137	16.27	118.77	.61	-132.43	29.71	292.05	.24	-137.13
12,44	9.70	71.137	13.46	116.76	.70	-128.82	27.03	289.31	.24	-135.60
12,44	9.80	71.137	16.27	118.77	.61	-132.43	29.71	292.05	.24	-137.13
13,44	9.70	70.788	13.27	116.53	.70	-127.85	27.08	289.04	.24	-134.77
13,44	9.80	70.788	15.95	118.03	.61	-131.38	29.64	291.36	.23	-136.29
14,44	9.70	70.846	13.21	116.57	.70	-127.88	26.99	289.04	.24	-134.85
14,44	9.80	70.846	15.88	118.01	.61	-131.42	29.54	291.32	.23	-136.37
15,44	9.70	70.874	13.19	116.58	.70	-127.89	26.94	289.03	.24	-134.89
15,44	9.80	70.874	15.85	118.00	.61	-131.43	29.49	291.30	.23	-136.41
16,44	9.70	71.002	13.06	116.66	.71	-127.95	26.74	289.02	.24	-135.06
16,44	9.80	71.002	15.70	117.96	.62	-131.51	29.26	291.22	.24	-136.59
17,44	9.70	71.080	12.99	116.71	.72	-127.98	26.61	289.01	.24	-135.17
17,44	9.80	71.080	15.60	117.94	.62	-131.56	29.12	291.18	.24	-136.70
18,44	9.70	71.149	12.92	116.76	.72	-128.02	26.50	289.01	.24	-135.26
18,44	9.80	71.149	15.52	117.93	.63	-131.60	29.00	291.13	.24	-136.79
19,44	9.70	71.199	12.88	116.79	.72	-128.04	26.42	289.01	.24	-135.33
19,44	9.80	71.199	15.47	117.92	.63	-131.63	28.91	291.11	.24	-136.86
20,44	9.70	71.298	12.78	116.86	.73	-128.08	26.26	289.00	.24	-135.46
20,44	9.80	71.298	15.35	117.90	.63	-131.68	28.74	291.05	.24	-137.00
21,44	9.70	71.448	12.64	116.96	.74	-128.15	26.03	288.99	.24	-135.67
21,44	9.80	71.448	15.18	117.88	.64	-131.77	28.48	290.97	.24	-137.21
22,44	9.70	71.448	12.64	116.96	.74	-128.15	26.03	288.99	.24	-135.67
22,44	9.80	71.448	15.18	117.88	.64	-131.77	28.48	290.97	.24	-137.21
23,44	9.70	71.055	12.33	116.82	.75	-126.85	25.97	288.72	.24	-134.65
23,44	9.80	71.055	14.89	117.18	.65	-130.38	28.27	290.22	.24	-136.17
24,44	9.70	71.165	12.23	116.91	.76	-126.90	25.80	288.73	.24	-134.79
24,44	9.80	71.165	14.58	117.20	.65	-130.44	28.09	290.17	.24	-136.32
25,44	9.70	71.213	12.18	116.95	.76	-126.92	25.73	288.73	.24	-134.86
25,44	9.80	71.213	14.52	117.21	.66	-130.46	28.00	290.16	.24	-136.39
26,44	9.70	71.439	11.98	117.15	.78	-127.01	25.33	288.74	.24	-135.16
26,44	9.80	71.439	14.29	117.25	.67	-130.58	27.63	290.08	.24	-136.70
27,44	9.70	71.543	11.89	117.24	.79	-127.05	25.22	288.74	.24	-136.30
27,44	9.80	71.543	14.17	117.28	.68	-130.64	27.45	290.05	.24	-136.84
28,44	9.70	71.657	11.79	117.34	.80	-127.09	25.04	288.75	.24	-135.45
28,44	9.80	71.657	14.05	117.31	.68	-130.70	27.26	290.01	.24	-137.00
29,44	9.70	71.877	11.60	117.55	.82	-127.17	24.71	288.77	.25	-135.75
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

SECTION VII

RECOMMENDATIONS FOR FURTHER REFINING THE PROGRAM

The following are suggested as subsequent tasks:

1. Verify the radome analysis program by using detailed design and measured data on an existing radome.

2. Obtain a suitable antenna simulation program and interface it with the radome program. Use the radome and antenna simulation programs to estimate the distortion of the antenna pattern due to the radome interference.

3. Verify the results from (2) above using measured data.

4. Perfect the radome simulation program with regard to core storage requirements and central processor time.

5. Document the radome/antenna simulation program as obtained using the foregoing steps.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-130.51	26.31	[illegible]	.24	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	117.47	[illegible]	[illegible]	24.75	[illegible]	.24	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.24	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24.31	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24.35	[illegible]	.24	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	117.07	.35	[illegible]	24.14	288.66	.25	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.73	[illegible]	25.17	[illegible]	.24	[illegible]
[illegible]	9.73	[illegible]	[illegible]	[illegible]	.87	[illegible]	23.93	288.69	.25	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.74	-129.71	25.94	[illegible]	.24	[illegible]
35.44	9.73	72.274	[illegible]	118.37	.93	-125.13	23.55	288.74	.25	-135.78
35.44	9.90	72.274	12.57	117.48	.76	-129.82	25.53	289.36	.25	-137.35
36.44	9.70	72.274	10.69	118.37	.93	-126.18	23.55	288.74	.25	-135.78
36.44	9.90	72.274	12.57	117.48	.76	-129.82	25.53	289.36	.25	-137.35
37.44	9.73	72.143	10.29	118.70	.93	-125.07	23.21	288.71	.25	-135.13
37.44	9.83	72.143	12.13	117.49	.79	-128.65	25.08	289.04	.25	-136.78
38.44	9.70	72.249	10.18	118.88	.95	-125.11	23.01	288.75	.25	-135.32
38.44	9.80	72.289	12.00	117.61	.80	-128.70	24.86	289.04	.25	-136.89
39.44	9.70	72.416	10.08	119.04	.96	-125.14	22.83	288.78	.26	-135.49
39.44	9.80	72.416	11.85	117.72	.81	-128.75	24.67	289.05	.25	-137.06
40.44	9.70	72.591	9.94	119.27	.98	-125.18	22.59	288.82	.26	-135.71
40.44	9.80	72.591	11.72	117.88	.83	-128.81	24.41	289.05	.25	-137.39
41.44	9.70	72.838	9.68	119.69	1.02	-125.04	22.17	288.91	.26	-135.93
41.44	9.80	72.838	11.40	118.16	.86	-128.69	23.95	289.04	.26	-137.53
42.44	9.78	72.830	9.68	119.69	1.02	-125.04	22.17	288.91	.26	-135.93
42.44	9.80	72.838	11.40	118.16	.86	-128.69	23.95	289.04	.26	-137.53

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